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REGIONAL GEOCHEMICAL SURVEYS CONDUCTED BY THE NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY FROM 1957 TO 1989

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REGIONAL GEOCHEMICAL SURVEYS CONDUCTED BY THE NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY FROM 1957 TO 1989

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INTRODUCTION

This report is a companion volume to the Geochemical Atlas of Nova Scotia, providing details of all geochemical exploration methods applied to date by the Department of Mines and Energy. The report contains material concerning the rationale for, and field and laboratory procedures concerning each type of survey.

The Geochemical Atlas of Nova Scotia (Fig. 1) is intended as a graphical representation of the surface chemical conditions as defined by geochemical surveys (Rogers, 1987). All data used in this final compilation are available on magnetic storage media at transcription cost to the user. Most of the geochemical data have been compiled at the 1:50 000 scale and summarized at the 1:250 000 scale. All of these compilations are designed as an aid to the user in order to understand the geochemical conditions pertaining to Nova Scotia.

Exploration geochemistry has been practiced in Nova Scotia since the 1950s and has resulted in a large number of maps, scientific reports and papers. This report is intended as a summary of the work conducted by Nova Scotia Department of Mines and Energy; any omissions are solely the authors' responsibility.

GEOCHEMICAL COVERAGE

Since 1957 a total of 13 regional geochemical surveys have been carried out in various physiographic regions of Nova Scotia by the Department of Mines and Energy and Geological Survey of Canada. Table 1 summarizes the 13 regional surveys by sample media, survey area, dates and source of funding. Most surveys were funded by cooperative agreements between the federal and provincial governments whose main intention was to stimulate economic activity through increased mineral exploration.

PHYSIOGRAPHY

Nova Scotia can be subdivided into 3 main physiographic areas: (1) lowlands (2) uplands and (3) highlands (Fig. 2). Most of the geochemical surveys were conducted in more than one physiographic region.

The lowlands consist of gently undulating plains of up to 200 m elevation. They are mostly underlain by Carboniferous or Triassic sediments. The lowland areas encompass the better agricultural land in the province, especially around Truro, Shubenacadie, Maitland and the Annapolis Valley.

The uplands occupy a broad area across mainland Nova Scotia which rises gently to the northwest and may represent the remnants of a broad Cretaceous erosion surface. The bedrock consists of Lower

Table 1. Regional geochemical surveys in Nova Scotia.

Sample Media/Region	Dates	Funding
(1) Stream Sediment		
A. Northern Nova Scotia	1986-87	Canada - Nova Scotia Mineral Development Agreement
B. Northern Nova Scotia	1982-83	Canada - Nova Scotia Cooperative Mineral Program
C. Highlands (Northern N.S.)	1971-78	Canada - Nova Scotia Department of Regional Economic Expansion
(2) Lake Sediment		
A. Southern Nova Scotia	1985	Canada - Nova Scotia Mineral Development Agreement
B. Eastern Cape Breton	1983	Canada - Nova Scotia Cooperative Mineral Program
C. Southern Nova Scotia	1977-78	Canada Department of Regional Economic Expansion Nova Scotia Mineral Development Agreement
(3) Surface Water Streams		
A. Northern Nova Scotia	1986-87	Canada - Nova Scotia Mineral Development Agreement
B. Northern Nova Scotia Lakes	1983	Canada - Nova Scotia Cooperative Mineral Program
C. Eastern Cape Breton	1983	Canada - Nova Scotia Cooperative Mineral Program
(4) Till		
A. South Mountain Batholith	1985-88	Canada - Nova Scotia Mineral Development Agreement
B. Northern Nova Scotia	1982-86	Canada - Nova Scotia Mineral Development Agreement
C. Meguma Zone	1977-85	Nova Scotia Department of Mines and Energy and the Canadian Department of Regional Economic Expansion
(5) Vegetation Tree Limbs/Bark		
A. Eastern Nova Scotia	1987	Canada - Nova Scotia Mineral Development Agreement

Palaeozoic metasedimentary rocks of the auriferous Meguma Group which have been intruded by Devonian to Carboniferous granitoids (Keppie and Meucke, 1979).

The highlands are found in northern Nova Scotia and form the rugged areas of the Cobequid and Antigonish Highlands, North Mountain and much of Cape Breton Island. The highland areas reach elevations of 200 to 230 m in the Cobequids and over 500 m on Cape Breton Island (Donohoe and Grantham, 1989). The highland areas are capped by a broad plateau, the possible remnant of a Cretaceous erosion surface. The bedrock consists of metamorphosed igneous and sedimentary rocks of Precambrian and Early Palaeozoic age, except the North Mountain which is composed of Triassic to Jurassic basalt.

1. RATIONALE FOR STREAM SEDIMENT SURVEYS IN NOVA SCOTIA

Stream sediment geochemistry is widely accepted as one of the classical methods available to the exploration geologist in the search for new ore deposits in Nova Scotia. Stream sediment geochemistry is also applied worldwide to the reconnaissance prospecting of large areas and is an efficient exploration tool (Meyer *et al.*, 1979). The low cost and ease of collection of stream sediments, coupled with their ability to detect individual deposits, indicate mine districts and outline

metallogenic provinces, is well documented (Meyer *et al.*, 1979; Plant *et al.*, 1989). The compositional variability found in stream sediments is largely caused by differing intensities of physical and chemical interactions of geology, climate and terrain within the drainage catchment basin. The isolation and computation of variability due to the presence of mineralization in the stream catchment is the main purpose in carrying out reconnaissance stream sediment surveys for mineral exploration.

The final design of a stream sediment survey for a particular area is, almost inevitably, a compromise solution. For stream sediments, the ability to detect all potentially mineralized areas has to be mitigated between the limitations of sampling, analytical and interpretative techniques, which all have to be accomplished within the available budget (Closs and Nicholl, 1989). The aims of the proposed survey must also be fully tested in an orientation survey to fine-tune methods for target selection (Levison *et al.*, 1980).

The extent of anomaly definition available for stream sediment samples is largely a function of the operative dilution, which in turn can be directly related to catchment basin size (Rose, 1975; Hawkes, 1976). The decision taken about which size of stream catchment to sample can therefore have a profound impact on the efficiency of anomaly definition and finally on the survey's effectiveness (Fig. 3). The application of catchment basin analysis to stream sediments using Hawkes' approach is a recent development in interpretation of regional geochemical patterns (Bonham-Carter and Goodfellow, 1984, 1986; Rogers *et al.*, in press).

In Nova Scotia, province-wide stream sediment surveys have been successfully conducted since 1956 in a number of stages related to the continuing development of analytical techniques (Table 2). The first stage of surveys in 1957 and 1958 (Fig. 4) used field-based colorimetric methods to estimate the heavy metal content of stream sediments in southwestern and northern Nova Scotia (Boyle *et al.*, 1958, 1963). Since this early pioneering work most subsequent attention during the second stage of surveys (Fig. 5) in the 1970s was centred on the highland areas of Precambrian and lower Palaeozoic rocks of northern Nova Scotia (Fig. 2). Most of this work was conducted in the Cobequid, Antigonish and Cape Breton Highlands (Shea, 1971, 1972, 1973, 1974, 1975; Bingley, 1975, 1977a, b, c, d; Bingley and Richardson, 1979; Bingley and Smith, 1976; MacNabb, 1975a, b, c, d, 1976 a, b, 1977; MacNabb *et al.*, 1976; MacKenzie, 1977; Richardson, 1979; Richardson and Bingley, 1978, 1979a, b). The second stage surveys featured the first application of hot acid partial extractions coupled with analysis by Atomic Absorption Spectrometry.

The 1970s surveys generally used a 330 m (1000 ft.) linear sample spacing with samples of silt and clay taken from the stream bed by hand. These exploration methods were designed for, and are most effective in, the search for base metal deposits assuming a hydromorphic secondary dispersion as the dominant weathering process (Levinson, 1980).

The combination of a hot acid partial extraction and Atomic Absorption Spectrometry was also used in northern Nova Scotia during the early 1980s (Fig. 6). These surveys marked the completion of the second stage of stream sediment geochemical surveys in Nova Scotia (Table 2).

Both previous stages of stream sediment surveys in northern Nova Scotia were designed to maximize geochemical contrast through sampling the secondary dispersion of heavy metals, especially from outcropping and oxidizing base metal sulphide deposits of Cu, Pb and Zn. These methods, however, are much less effective for elements mechanically dispersed as refractory grains, such as Sn and W, or for elements only found in very low concentrations, such as Au. To this end, in 1986 and 1987 the third stage of stream sediment surveys using heavy minerals was planned (Fig. 7). This survey was designed to investigate the precious metal potential of northern Nova Scotia (Rogers and Mills, 1986). Orientation surveys conducted in 1983 and 1985 showded that collection of bulk samples of stream

Table 2. Stages of application of geochemical sampling to Nova Scotia.

		AREA km²	SAMPLES	DENSITY
1. LAKE SEDIMENTS				
A. STAGE 1				
1977/78	Meguma Zone	26 991.63	3416	7.90
1983	Northern N.S.	3084.88	414	7.45
B. STAGE 2				
1985	Meguma Zone	22 935.98	2951	7.77
2. STREAM SEDIMENTS				
A. STAGE 1				
1957/58	Meguma Zone + Northern N.S.		8800	4.84
B. STAGE 2				
1971/73	Cobequid Highlands	2100.49	5870	2.80
1974/75	Antigonish Highlands	2201.50	6870	3.12
1973/78	Cape Breton Island	11 965.80	14,450	4.28
1982/83	Northern N.S.	19 278.26	4500	4.28
C. STAGE 3				
1986/87	Northern N.S.	22 528.34	3000	7.51
3. TILLS				
1977/82	Meguma Zone	30 232.46	1120	26.99
1982/86	Northern N.S.	12 360.37	941	13.12
1984/89	South Mountain Batholith	10 000.00	1700	5.88
4. VEGETATION				
1987/Spruce Bark	Meguma Zone	5000.00	107	46.73
1987/Balsam Fir	Meguma Zone	5000.00	593	8.43

NOTE:

Stage 1 - Partial acid extraction, estimates chemical weathering
Stage 2 - Total acid extraction, estimates mechanical and chemical weathering
Stage 3 - Stages 1 and 2 plus analysis for major elements

sediment provide more reliable and reproducible results compared to those from panning (Rogers and Mills, 1986). A combination of field sieving and use of two analytical size fractions was used to maximize response for gold (Rogers and Mills, 1986). The coarse fraction (-250μm to 62.5μm) provides for the detection of mechanical dispersion whereas the fine fraction (-62.5μm) provides for the detection of chemical dispersion (Rogers and Mills, 1986).

The fine fraction was analyzed using a 'total' extraction coupled with Atomic Emission Spectroscopy by Inductively Coupled Plasma. This 'total' extraction will provide analyses more directly related to bedrock composition, unlike the previous partial extraction techniques of stages one and two. Apart from the mineral exploration uses of the data, this information is also of application to environmental studies. This geochemical mapping approach will allow more direct comparisons to be made between bedrock composition and geochemical patterns in stream sediments (Rogers and Mills. 1986).

1A. 1957 AND 1958 REGIONAL STREAM SEDIMENT SURVEYS

Introduction

This survey was conducted over most of mainland Nova Scotia (Fig. 4) and represents the first regional stream sediment survey for the province (Boyle *et al.*, 1958; Holman, 1959a, b, c, d). The aim of the survey was to apply geochemistry to mineral exploration in order to outline favourable target areas by studying the regional variations of Cu, Pb and Zn in stream sediment silts (Holman, 1963). This survey represents the first stage of stream sediment geochemistry in Nova Scotia (Table 2) and, indeed, was one of the first Canadian attempts at regional geochemistry of this type (Boyle *et al.*, 1958; Holman, 1959a, b, c, d).

Approximately 8800 samples were taken from an area of 42 600 km^2: a sampling density of 1 per 4.8 km^2 (Table 2).

Field Methodology (from Holman, 1963)

Access was achieved mainly along roads or tracks at stream intersections where samples of about 0.3 kg of silt and sand were hand grabbed from the stream bed. All samples were collected well upstream from road and stream intersection to avoid contamination. Samples were placed in Kraft paper envelopes and in an outer polyethylene bag for safety during transport. The samples were air dried at the base camp prior to shipping to the laboratory. Field observations regarding stream characteristics, geology and topography were also taken with a view to later computer data reduction (Holman, 1963).

Laboratory Procedures (after Holman, 1963)

The dry samples were sieved to pass through an 80 mesh (200μm) screen to yield the analytical fraction; the oversize material was retained for future reference. Field analysis was initially performed on wet, unsieved samples using the colorimetric dithizone method of Bloom (1955) for all three metals and for copper (Holman, 1956). Subsequently, most colorimetric analysis was done at the base camp using a fixed amount of dithizone (Holman, 1956). A set of zinc standards were used for calibration and the 'total heavy metal' concentration is therefore expressed as zinc units. The dried, sieved fraction of each sample was subsequently analyzed for 'total' Cu, Zn and Pb (Gilbert, 1959).

1B. 1971-78 STREAM SEDIMENT SURVEYS

Introduction

From 1971 to 1978 regional geochemical stream sediment surveys by the Department of Mines and Energy concentrated on the highland areas of northern Nova Scotia: the Cobequid Highlands, the Antigonish Highlands and the Cape Breton Highlands (Fig. 5). These highland areas were selected as having the greatest potential for base metal mineralization. The main objective of these projects was identification of target areas for additional mineral exploration (MacNabb *et al.*, 1976). The Stage 2 surveys used a combination of hand-grabbed silt samples with subsequent hot acid partial extraction analytical techniques. The surveys were planned and executed using the hydromorphic geochemical dispersion model principally for sulphide ore bodies. A breakdown of the areas sampled during the years of the survey is summarized in Table 3. These Stage 2 surveys used different sampling and analytical techniques than later surveys and, therefore, comparison between results from this 1971-1978 survey program and data from the Stage 2 1982-84 stream sediment surveys is not advisable.

Field Methodology

In these surveys samples were collected by the hand grab method, which allowed for the collection of large numbers of samples each day. The objective of this sampling technique was to obtain approximately 1-2 lb. of stream sediment. Care was taken to obtain a minimum of 10% organic material in each sample to maximize geochemical contrast. The wet sediment samples were placed in Kraft paper bags for later transport and processing. All accessible streams were sampled at 330 m intervals. Along with the regular sampling, a field duplicate and a reference sample were included in each batch of 20 samples (Richardson and Bingley, 1979).

At each sample location field observations of the following were recorded on computer index cards: sample number, date, UTM coordinates, physiography, gravel fragment composition, stream temperature, pH, width, depth, flow rate and turbidity. All field observations were later transferred to magnetic tape for data reduction using a mainframe computer (MacNabb, 1977).

Laboratory Procedures

The silt samples dried out to a certain extent in their paper envelopes in the field, but final oven drying at 80 - 100°C was carried out at the Nova Scotia Technical College. The samples were then dry screened to obtain the - 60 mesh material for analysis. The samples were then analyzed for a suite of elements which varied with the area surveyed (Fig. 5). Analytical methods for each survey are summarized in Appendix A.

1C. 1982-83 STREAM SEDIMENT SURVEY

Introduction

This survey was planned to complete the stream sediment coverage of northern Nova Scotia for areas not sampled during the 1970s (Fig. 5 and Table 1). The 1982-83 stream sediment survey covered northern mainland Nova Scotia and Cape Breton Island (Fig. 6). This project was funded by the Canada - Nova Scotia Cooperative Mineral Program 1981-84. The survey covered approximately 10 000 km^2 of northern Nova Scotia with a linear sample spacing of 2 km (Rogers, 1983). About 4100 stream sediment samples were collected during this survey (Rogers and MacDonald, 1984a, b). This

Table 3. Sampling information for Stage 2 (1971 to 1978) stream sediment sampling of the highland areas of Nova Scotia.

YEAR	AREA	NUMBER OF SAMPLES TAKEN	AREA km^2	DENSITY
	COBEQUID HIGHLANDS	5871	2100.49	2.80
1971	COBEQUID HIGHLANDS	1379		
1972	COBEQUID HIGHLANDS	1274		
1973	COBEQUID HIGHLANDS	3218		
	ANTIGONISH HIGHLANDS	7000	2201.5	3.12
1974	ANTIGONISH	3470		
1974	CAPE GEORGE	1110		
1975	NEW GLASGOW	2420		
	CAPE BRETON HIGHLANDS	14,450	11 965.8	1.20
1973	CHETICAMP	3048		
1974	LAKE AINSLIE	3000		
1975	BADDECK	1690		
1975	WRECKCOVE	1150		
1977	PORT HOOD	3500		
1978	PORT HAWKESBURY	2800		
GRAND TOTAL:		27,321		

Stage 2 survey was designed to determine the variation in regional geochemical patterns of stream sediments as an aid to mineral exploration and environmental studies (Rogers, 1983; Rogers and MacDonald, 1983).

The survey model assumed a dominant hydromorphic dispersion as the product of chemical weathering in the surficial environment. Subsequent studies have demonstrated the important role that secondary process, especially water pH, can play in determining the levels of Fe, Mn, Ni, Ca, Cu, Zn and As in stream sediments (Bonham-Carter *et al.*, 1987). This is especially so in lowland areas of the Carboniferous sedimentary basins of northern Nova Scotia. In these areas, false geochemical anomalies can be easily generated in stream sediments by secondary weathering effects in areas with acidic surface groundwater (Rogers *et al.*, 1986).

The 1982-83 stream sediment survey differed from the earlier (1970s) surveys in two important respects: sample collection method and sample spacing. Orientation surveys (Rogers and MacDonald, 1984a, b) confirm that the survey methods adopted were appropriate and able to detect significant mineral deposits. Target deposits like those at Meat Cove (Zn) or Coxheath (Cu-Mo) are easily detected within the stream catchment basin size selected for this survey. Sampling of the active sediment bedload by field sieving increases contrast by preconcentration during sieving (Plant, 1971).

This increase in contrast also allows a wider sample spacing of 2 km to be used and still be effective when compared to 300 m spacing employed by the hand-grab method employed in the 1970s.

Field Methodology

Wherever possible first, second or third order stream drainages were sampled in order to minimize dilution and present smaller potential targets for follow-up study (Hawkes, 1976). At each sample site the zone of active sediment transport was sampled with a trowel or scoop. The sampling devices were all made of stainless steel, which had any metal-based paint removed before sampling. Sample sites were selected at roadside locations wherever possible with access mainly by light truck. Where appropriate helicopters, boats or fly camps were used in the more inaccessible areas (Rogers and MacDonald, 1984a, b). Sites were selected upstream of culverts at least 50 m away from the road. All field observations were recorded on computer cards and in field notebooks (Garrett, 1974; Garrett *et al.*, 1980). Each sampling site was selected in order to maximize sampling of the bedload during flood conditions, and therefore of the whole drainage catchment (Ohensen *et al.*, 1989).

Scoops of gravel, sand and silt from the stream bedload were placed on a nylon 1 mm (Nytex) sieve for on-site sieving. The sieve housing was approximately 45 cm in diameter and made of wood with plastic screws to secure the sieve cloth. The collecting pan used was a plastic gold pan into which about 500 g of -1 mm material were finally collected. The use of plastic and wood as construction materials is necessary to minimize metal contamination. The material on top of the sieve cloth was agitated by hand to speed up the process, the siever used a rubber glove to protect the hands and avoid contamination. During sieving care was taken to use minimal amounts of water to restrict fines loss in water escaping from the collection pan. After sufficient material was obtained the sample was allowed to stand, usually while field notes were taken, to avoid loss of suspended matter. At this time the pH of the stream water was measured along with a water sample (see Water Surveys). The whole sample was then poured into a Kraft paper bag which was then placed into a polythene bag as a further protection during transit.

At the end of each day, sample locations were plotted on 1:50 000 scale base maps and the samples were air dried. The stream sediment samples were placed on specially constructed, covered drying racks to dry over a period of two or three days, depending on the weather. Air drying was used in preference to laboratory oven drying to minimize loss of elemental mercury, which vaporizes at relatively low temperatures.

Quality control procedures of the Geological Survey of Canada were followed throughout the survey (Garrett *et al.*, 1980). Samples were collected in batches of 20 which included one reference standard, two field duplicates and two analytical duplicate samples. The field duplicate pair formed half of the analytical (blind) duplicate pair is an unbalanced sampling design. The use of the unbalanced design achieves a greater efficiency of quality control with a much lower amount of duplicate sampling (Fig. 8, from Garrett *et al.*, 1980).

Laboratory Procedures

Each batch of 20 air-dried samples was submitted to the laboratory for dry sieving. About 50 g of - 64 μm material were collected for analysis. Oversize material was returned to the sample bag and stored. The vials of sieved material were sent to a commercial laboratory for analysis (Lund, 1987). After appropriate checking the analytical data were merged with the field card information in the computer in preparation for statistical analysis (Garrett *et al.*, 1980).

All data from the 1982 and 1983 survey have been plotted on 1:50 000 scale map sheets and released as a series of open file maps (Rogers and MacDonald, 1984a-g; 1986a-t and 1987 a-w). Details of analytical methods are given in Appendix A.

1D. 1986-87 STREAM SEDIMENT SURVEY

Introduction

A Stage 3 regional geochemical stream sediment survey was conducted in northern mainland Nova Scotia and Cape Breton Island during 1986 and 1987 (Fig. 7). The survey was principally designed for precious metal exploration, with the aim of defining new mineral potential outside of the traditional gold producing areas of the Meguma Zone (Rogers and Mills, 1986; Rogers, 1989a, b). As a Stage 3 survey, both mechanical and hydromorphic dispersion were examined from bulk samples using two analytical fractions to maximize the gold response (Rogers and Mills, 1986). This type of survey is both costly and labour intensive, as large samples are required to overcome the nugget effect for efficient gold exploration (Harris, 1982; Fletcher and Day, 1988). In view of the nugget effect and budgetary limitations a sampling density of approximately 1 sample per 7.5 km^2 was employed for the survey. Analytical data for the two fractions and surface waters are found in Mills, 1989. Analytical methods are listed in Appendix A.

Field Methodology

After careful site selection to avoid contamination, first or second order streams were sampled when enough sediment was available for a 5 kg sample. At each sample site (mostly stream bars), suitable traps were selected, such as areas behind boulders or logs near or at the water level. Scoops of gravel were taken from the stream bed using a steel muck scoop. All metallic paint was removed from the muck scoop prior to sampling. The material was sieved on-site using a 1 mm nylon mesh and collected into a plastic pan. The sample was then poured into a plastic bag, including all of the water used during sieving. Care was taken to avoid sample loss via excess water. At the field base camp the stream sediment samples were allowed to stand for a minimum of 48 hours to allow fine gold particles to settle (Mills, 1989). After 48 hours the excess water was siphoned off using a plastic tube and the sample was packed for shipment to the laboratory. For each batch of 20 samples collected, a field duplicate sample (Fig. 8) was taken at one location where there was enough sediment for two samples. At each sample site, notes were recorded on field cards, including comments on the sample site. These notes were later transferred into the computer as D-Base III • files (Mills, 1989).

Laboratory Procedures

The stream sediment samples were wet sieved in the laboratory with retention of the -60+230 (-250 +62.5 μm) mesh and -230 mesh (-62.5μm) fractions (Fig. 9). The coarse -60+230 mesh (-250 + 62.5μm) fraction was immersed in a heavy liquid, specific gravity (SG) 2.79, to separate out the heavier minerals from each sample. In 1986, tetrabromoethane was used as the heavy liquid and in 1987 methylene iodide, diluted to an equivalent SG of 2.79. This change was necessary as bromine contamination of the 1986 samples was detected upon analysis by Instrumental Neutron Activation. Excess bromine in the epithermally irradiated samples produced a number of radioactive isotopes. These isotopes continuously emit radioactivity at intensities that mask the signal from other elements. This process, therefore, produces noise and causes elevated detection limits for gold and molybdenum. Most of these 1986 results are therefore highly suspect (Mills, 1989). Tests were made to determine the cause of the bromine contamination (Mills, pers. comm. 1987). Incomplete washing with acetone during mineral separation was concluded as the probable cause. In view of this, in 1987 a switch was

made to methylene iodide. Additionally, manual acetone washing was also replaced with cleaning in a sonic bath to ensure complete cleaning (Cole, pers. comm. 1989).

Each of the two size fractions were analyzed using the methods outlined in Appendix A and for elements listed in Figure 7.

2. RATIONALE FOR LAKE SEDIMENT SURVEYS IN NOVA SCOTIA

The first stage of lake sediment surveys saw the application of hydromorphic models to surveys in the Meguma Zone and southeastern Cape Breton Island (Fig. 10). These surveys were performed to compliment the stream sediment surveys in northern Nova Scotia (Fig. 6). Lake sediment surveys were restricted to lowland areas of poor drainage based on the assumption that stream sediment exploration methods were not functional in these areas (Jones, 1975). This assumption is erroneous, as streams in these lowland areas do contain silt and have been used successfully for exploration (Miller, 1982; Rogers and MacDonald, 1984a, b).

The second stage of lake sediment surveys concerned the re-analysis of archived material from the Meguma Zone (Fig. 11) using hydromorphic and mechanical dispersion models (Rogers, 1988).

Regional centre-lake bottom sediment geochemical surveys in Nova Scotia, as in other parts of Canada, have been widely used as a cost-effective and accurate exploration tool to rapidly cover and assess areas for follow-up study (Coker *et al.*, 1979, 1982). Previous 'traditional' lake sediment exploration models (Timperley and Allan, 1974) have assumed the pre-eminence of hydromorphic processes in lake systems to generate anomaly-producing, metal-bearing organic complexes (Fig. 12). Regional lake sediment surveys in Nova Scotia were performed as part of the Geological Survey of Canada National Geochemical Reconaissance (NGR) Program (Lund, 1987).

Recent limnological investigations by Ogden (1986) indicate the presence of a tardelimnion, a zone of no groundwater movement, in most Nova Scotian lake drainage systems. It is only within a limited outer zone, the perilimnion, that groundwater interaction with a lake's water column is found to be significant (Fig. 10). A new exploration model for lake sediment geochemical surveys in Nova Scotia (Fig. 13) was developed by Rogers (1988) to encompass the primary and dominant role that surface processes have in the input of material to lake sediment basins. Lake sediment geochemical exploration models for Nova Scotia also assume that the lake catchment basin acts as the area of influence for each sample (Wright *et al.*, 1988). Additionally, lake drainage systems are now seen to act as dynamic and responsive collectors of geochemical information (Ogden and Rogers, 1988; Rogers, 1988).

One of the fundamental tenets of this new exploration model is that samples of gyttja, the organic-rich ooze used as the normal sampling medium, are fully representative of the composition of the lake catchment area. Input to lake catchment basins is largely dominated by surface weathering components with little groundwater interaction into the lake water column (Ogden, 1986, 1987). Lake basins can therefore act as geochemical sinks trapping a mixture of chemical and mechanical weathering components (Fig. 14). Scanning electron microscope studies of heavy mineral separates from lake sediments have revealed numerous, discrete, particulate and sometimes unexpected mineral phases in the gyttja (Rogers, 1988). Most heavy mineral particles detected in Nova Scotian lakes are small, a maximum of 240 μm in length, and usually angular. The angularity, and therefore lack of erosion, indicates relatively short transport distances from either a direct bedrock or till source (Rogers and Garrett, 1987). At East Kemptville, for example, the anomalous Moosefly Lake catchment basin contains tin-bearing tills that indicate transport distances of at least 1000 m (Rogers and Garrett, 1987).

Following the discovery of particulate cassiterite, monazite and zircon in gyttja from East Kemptville, similar 50 kg bulk samples were collected from lakes on the Halifax Peninsula that had gold anomalies. A variety of mineral species were detected including mineral phases previously unreported from Nova Scotia (Rogers, 1988). In Figure 14 heavy minerals detected from the granitoid Halifax Peninsula are compared to those from a lake developed on Meguma Group lithologies at Sealoam Lake, Halifax County. This study also documented the presence of the unusual tin minerals hoschildite (SnO_2) and herzenbergite (SnS) found in lakes developed on both granitoid and Meguma Group lithologies. These minerals were first reported from Bolivia (Dana, 1944) and this is their first reported occurrence in Nova Scotia. Hoschildite has also been detected in a quartz vein from the Forest Hill gold deposit (Watson, personal communication, 1987).

The variety of mineral species present in the lakes studied (Fig. 14) reflects some basic differences between lakes developed on granitoid rocks and metasedimentary Meguma Group rocks in the Meguma Zone (Rogers *et al.*, 1984). The presence and preservation of sulphides such as pyrite, arsenopyrite, sphalerite and galena in the Meguma Group lakes contrasts with the predominance of oxides such as zincite found in granitoid lakes. There would appear to be no perceptible difference between the lakes on the basis of other phases. The East Kemptville tin deposit is surrounded by lakes that contain discrete particles of cassiterite in bottom sediment samples (Rogers and Garrett, 1987). The detection of free gold in Meguma Zone lake sediments (Rogers, 1988) underlines the important role that mechanical weathering can play in anomaly generation and recognition for lake sediment geochemical surveys. In Nova Scotia, distinctive bedrock metallogenic domains have been recognized in the Meguma Zone (Chatterjee, 1983). It is possible to identify these bedrock metallogenic domains by their multi-element geochemical associations in lake sediments developed over the underlying strata (Rogers *et al.*, 1990). The anomaly patterns found in lake sediments, therefore, reflect the presence of bedrock mineralization either by sampling a subcropping rock unit or a surface till. The partition of anomaly response between hydromorphic and mechanical weathering processes in lake sediments allows their use in exploration for lithophile elements such as Sn, W, Rb, F and Nb. This is a new application for lake sediment geochemistry (Rogers, 1987; Hornbrook, 1989).

The application of lake sediment sampling in Nova Scotia geochemical surveys follows a similar development to that of stream sediments. Technological change produced new analytical methods which were then applied to the lake sediment samples. The development of new exploration methodologies recognizes a dual process for lake sediment anomaly generation to include hydromorphic and mechanical weathering effects.

2A. 1977-78 LAKE SEDIMENT SURVEY

Introduction

A regional centre-lake bottom sediment survey was conducted in southern Nova Scotia in 1977 and 1978 (Fig. 10). Approximately 3400 samples were collected from southern Nova Scotia, a sampling density of 1 per 7.9 km^2 over an area of 27 000 km^2 (Bingley and Richardson, 1978b; Richardson and Bingley, 1979). The project was funded by the 1975-80 Canada Department of Regional Economic Expansion Agreement - Nova Scotia (Table 1). The survey was conducted as part of the National Geochemical Reconnaissance Program of the Geological Survey of Canada (Hornbrook, 1989). The data were released as a series of open file maps at 1:100 000 scale containing data for Cu, Pb, Zn, Ni, Co, Fe, Mn, Ca, Mg, Mo, Hg, As and U (Bingley and Richardson, 1978a; Richardson and Bingley, 1980) and as colour computer plots at 1:200 000 scale (Garrett *et al.*, 1982). A preliminary statistical analysis indicated that trace element values of lake sediment samples had close association to the

composition of the underlying rock type (Richardson and Bingley, 1979). Table 4 contains details of the trace element levels of lake sediments developed on various lithological units (Rogers, 1989).

Table 4. Summary statistics for the total lake sediment dataset.

Element	Unit	Arithmetic Mean	Standard Deviation	CV%*	Minimum	Maximum	Number of Analyses
Cu	ppm	12.6	8.3	66.3	1.00	94.0	2947
Pb	ppm	14.8	12.8	86.4	1.00	327.0	2947
Zn	ppm	58.0	47.1	81.2	1.00	510.0	2947
Ag	ppm	0.2	0.5	264.1	0.10	22.6	2947
F	ppm	119.0	78.6	66.1	20.00	990.0	2947
Li	ppm	8.7	8.6	98.4	1.00	78.0	2947
Nb	ppm	2.5	3.0	119.3	1.00	74.0	2920
Rb	ppm	37.5	31.1	83.1	2.00	521.0	2914
Sn	ppm	2.3	2.1	92.8	1.00	36.0	2933
Zr	ppm	86.8	66.9	77.1	1.00	565.0	2914
Ti	%	0.2	1.3	573.5	0.01	69.0	2914
Au	ppb	6.3	25.8	413.1	1.00	853.0	2886
Sb	ppm	0.3	0.3	96.1	0.10	10.2	2936
As	ppm	12.0	38.2	318.4	0.40	999.9	2936
Th	ppm	3.4	2.2	64.8	0.20	23.1	2936
W	ppm	1.5	8.07	548.4	0.30	434.0	2935

*Coefficient of Variation

Field Methodology

The field collection program used methods developed by Hornbrook and coworkers at the Geological Survey of Canada (Hornbrook *et al.*, 1975). Samples were collected from the deepest basins, usually in the centre of the lakes, using a float equipped helicopter (Bell Jet Ranger). The deeper basins contain the most representative samples (Hornbrook, 1989) and are usually recognized from the air by their darker waters. The lake sediment samples were normally obtained using a gravity corer, which was mounted on a housing belted to the aircraft's fuselage (Coker *et al.*, 1979). The gravity corer or 'torpedo' attached to a rope is normally allowed to free fall from the helicopter and is recovered using a hand-operated winch. The sample is retained in the 'torpedo' by a butterfly valve at the end and the slurry is extracted by inverting the torpedo. The field crew consists of two people who dismount onto the floats from the helicopter once it lands on the water. One person normally drops the torpedo and raises it again while the other takes a surface water sample and fills out a computer field card. Depending on circumstances, most samples can be taken in 1 minute or less. Using rotating field crews, sampling rates of up to 120 per day are not unreasonable (Rogers, 1987).

During the flight and in between stops, a coded computer field card was filled out to record details such as water depth, composition, colour, suspended matter and basin area (Garrett, 1974). Each sample was placed in a wet-strength Kraft paper envelope and stored upright in a plastic crate to avoid spillage. The samples were stored on a wooden drying rack and partially air dried (see Stream Sediments). The samples were then boxed and shipped to the laboratory for sample preparation.

Laboratory Procedures

The samples were sent to the Technical University of Nova Scotia (Halifax, N. S.) for sample preparation and analysis. As most samples were only partially dried in the field additional drying was performed. Lake sediment samples were air-dried in netting stretched across and supported by wooden frames. Oven drying at 80°C was used on these samples. The high organic content of lake sediments usually promotes the production of hard clay balls in the dried samples. These were disaggregated either by pounding with a pestle or by about 30 seconds in a steel shatter box (Cole, pers. comm., 1989). The dry samples were bottled directly with no sieving. The samples were then analyzed for 15 elements as listed in Figure 10 by the methods outlined in Appendix A.

2B. 1983 LAKE SEDIMENT SURVEY

Introduction

A regional geochemical lake sediment sampling program was completed for eastern Cape Breton Island during the 1983 stream sediment project (Fig. 10). The aim of the survey was to compare the results from this survey to those from the stream sediment survey in a poorly drained area (Rogers, 1987). Approximately 314 lake samples were collected from this area of Cape Breton Island, at a sampling density of 1 per 7.45 km^2. The data were released as a series of 1:50 000 scale maps for Cu, Pb, Zn, Ag, Fe, Mn, Co, Ni, As, Mg, U, Mo, Cd, V, F and LOI (Rogers and MacDonald, 1987a-w). The methods and aim of the survey were identical to those of the 1977-78 Stage 1 survey.

Field Methodology

See Lakes 1977-78.

Laboratory Procedures

See Lakes 1977-78.

The only exception is that the dried samples were sieved to pass through a 200 mesh (62.5μm) screen. Any excess material was returned to the sample bag and the original sample stored.

2C. 1984 LAKE SEDIMENT SAMPLE RE-ANALYSIS

Introduction

In 1984 a small pilot study was conducted using archived lake sediment samples from the East Kemptville tin deposit (Rogers and MacDonald, 1985). The pilot study was planned to investigate the application of lake sediment geochemistry to exploration for lithophile elements such as Sn or W (Rogers and Garrett, 1987). A subset of 55 samples was analysed for Sn, Rb, F and Cl (Rogers and Garrett, 1987). The East Kemptville deposit was reflected in lake sediment anomalies for Sn, Rb and F in a halo pattern at some distance away from the mine (Fig. 15).

Following the success of this pilot project, about 3000 archived lake sediment samples from the 1977-78 survey were submitted for analysis for Cu, Pb, Zn, Th, Ti, Sb, Sn, Zr, Nb, Au, W, Rb, Li and F (Fig. 12). Details of the analytical methods are given in Appendix A.

The results were published at 1:250 000 scale (Rogers *et al.*, 1985; Rogers, 1989). Interpretation of the dataset has been published in a series of scientific papers and conference presentations (Rogers 1987; Rogers and Garrett, 1987; Wright *et al.*, 1988; Rogers *et al.*, 1990).

Field Methodology

There was no sample collection required for this survey as archived lake samples were used.

Laboratory Procedures

There was no laboratory work done as all samples were from the 1977-78 survey. The analytical methods used in the survey are listed in Appendix A.

3. RATIONALE FOR TILL SURVEYS IN NOVA SCOTIA

Nova Scotia, like most of Canada, was extensively glaciated in the Quaternary Period. This glacial action resulted in the creation of distinct landforms in Atlantic Canada, largely attributable to intermittent ice advance and retreat (Grant, 1963). These many distinctive landforms are all developed from the interplay of various depositional and erosional conditions of the Wisconsonan glaciers (Stea *et al.*, 1988). Large parts of Nova Scotia are covered by glacial deposits of various thickness, including till, whose composition reflects the nature of the underlying bedrock (Stea and O'Reilly, 1982). Glacial action, either by continental ice sheets or from local ice centres, has produced a complex pattern of dispersal in the landscape of Nova Scotia (Stea *et al.*, 1988). The till sheets that cover the various bedrock units have a distinct provenance, geochemistry and dispersal. The composition of these till sheets is due to the interplay of topography and ice movements during successive glaciations (Stea *et al.*, 1988). The mapping and sampling of these till sheets in Nova Scotia have been used to assist mineral exploration.

The use of till sampling in mineral exploration is well documented by Coker and Di Labio (1989). Effective design of till exploration programs can only be achieved where the nature of glacial dispersal is identified (Shilts, 1975). The dispersal of source material down-ice can produce a ribbon or fan-shaped train (Fig. 16) (Prest, 1977; Miller, 1984) with a chemically distinctive head and tail (Fig. 17). The tail is usually of a much greater size than the head and is, therefore, the main target for till sampling programs. The recognition of this dispersal tail, and tracing it back up-ice to source, is the principal aim of a till exploration survey (Coker and Di Labio, 1989). Dispersal can occur at a variety of scales from metres to hundreds of kilometres and can often produce a composite dispersal deposit through the incorporation and entrainment of material from earlier dispersal trains, as is common in Nova Scotia (Stea *et al.*, 1988).

Most till geochemical programs use surface materials and their post-glacial geochemical weathering properties (Shilts, 1975). Studies by Haldorsen (1977, 1983) and Taipale *et al.* (1986) indicate that till-forming processes, in addition to bedrock composition, are important in understanding till geochemical patterns. Most chalcophile elements, when occurring as sulphides, are normally weathered in surface tills and these elements are hydromorphically mobilized and become enriched in fine size ranges (Shilts, 1975; Stea, 1982a, b). This is in contrast to lithophile elements which tend to be enriched in coarser fractions (Coker and DiLabio, 1989). Gold, in general, tends to be found in greatest concentrations in the fine size ranges, although the processes of gold enrichment in till can be very complex (Coker and DiLabio, 1989).

In Nova Scotia till reconnaissance mapping and geochemistry at 1:100 000 scale have been applied since 1977 (Stea and Fowler, 1979b). The surveys have combined lithostratigraphic mapping of till units as an aid to exploration and to interpreting other geochemical surveys, for example lake sediment surveys (Rogers *et al.*, 1984).

3A. 1977-82 TILL SURVEY - MEGUMA ZONE

Introduction

From 1977 to 1982 a till mapping project was conducted in the Meguma Zone of Nova Scotia (Fig. 18, Table 1). The aim of the project was to map the major till types and classify them using lithological, textural and trace element genetic characteristics (Stea and Fowler, 1979a, b). The principal geochemical thrust of the project was to use the trace element content of tills as an aid to interpreting the regional lake sediment survey in the same area (Stea and Fowler, 1979a, b; Stea and O'Reilly, 1982).

The survey produced a series of colour surficial maps delineating lithostratigraphic units as distinct till facies based on their clast content, sedimentology and trace element geochemistry (Stea and Fowler, 1979a; 1981a, b; Stea 1982, 1983; Stea and Grant, 1982). Full details of all papers and related surveys are found in Stea and Brisco (1984). Of particular note is the paper by Stea and O'Reilly (1982) which discusses till geochemistry in relation to the metallogenesis of the Meguma Zone.

During 1982 a detailed study of till exposures at the Forest Hill gold district was conducted to investigate the till stratigraphy and the three-dimensional dispersal of gold and related elements (MacEachern *et al.*, 1984; MacEachern and Stea, 1985). The area has a number of till units indicating polyphase ice movement patterns (Stea *et al.*, 1988). Hydromorphic redistribution of gold and other elements was noted in the fine fractions related to post-glacial chemical activity. This effect was also noted at the Fifteen Mile Stream gold deposit (MacEachern, 1983; MacEachern and Stea, 1987). The dispersal trains contained gold as distinct flakes and nuggets, indicating little abrasion during glacial transport. The gold dispersal trains were mapped as three-dimensional bodies coming to the surface 200 - 300 m down-ice from source gold-bearing veins (MacEachern and Stea, 1985). This is in contrast to work by DiLabio (1982a, b) who indicated a dispersal of 1900 m for gold in till down-ice from the Oldham gold deposit.

Field Methodology

Samples were collected from available exposures along road sections, streams and sea cliffs at an average depth of 2 m. Thicker sections were sampled at 0.5 to 1.0 m intervals (Stea and Fowler, 1979a, b). Each sample of 2 to 4 kg of till was examined for texturel, fabric and pebble lithology. Air photographs were extensively used to identify drumlins and other landforms. When sufficient exposure was not present, pits were dug by hand with a steel bar and long-handled shovel. All samples were tagged and placed in polyethylene bags for transport.

Laboratory Procedures

All samples were submitted to the Laboratory for the Investigation of Minerals, Technical University of Nova Scotia, for preparation and analysis.

The samples were prepared by the process of wet screening, centrifuging and heavy mineral separation (Fig. 19). The process was designed to obtain clay (-2 μm) particles to obtain maximum

geochemical contrast (Shilts, 1975). The heavy mineral separation used tetrabromoethane (SG 2.96) to separate fine to medium sand fractions (62.5-300 μm) from the till sample. This fraction was chosen because the basal zones of glaciers tend to concentrate heavy minerals in the finer grain sizes (Dreimanis and Vagners, 1971).

All samples were analysed for Cu, Pb, Zn, Ag, Cd, Ni, Co, Fe, Mn, As, Mo, U, Ca, Mg, Sn and W (Fig. 18) by methods listed in Appendix A.

3B. 1982-86 TILL SURVEY - NORTHERN MAINLAND NOVA SCOTIA

Introduction

From 1982 to 1986 a regional till sampling survey was conducted in northern mainland Nova Scotia (Stea and Finck, 1984; Stea *et al.*, 1985, 1986, 1988). A total of 941 till samples were collected at approximately 1 sample per 13 km^2 (Fig. 20). The project was an extension of the earlier Meguma Zone surveys (Section 4A).

The surficial geology and geochemical data were released as a series of 1:100 000 scale maps (Stea and Finck 1984; Stea *et al.*, 1985; Turner and Stea, 1987a, b, c; 1988a, b, c, d; Stea and Myers, 1990). The open file geochemical maps include statistics for each element with threshold values taken as the 95th percentile for each map sheet (Turner and Stea, 1988a, b, c, d). The computed threshold values are portrayed in a star symbol in order to illustrate the multi-element character of defined anomalies (Turner and Stea, 1987b, 1988a, b, c, d). The results from this survey have been published as scientific papers summarizing the regional till geochemical trends (Stea *et al.*, 1986; Turner and Stea, 1990).

Field Methodology

Methods were similar to those from earlier surveys with the addition of a preliminary aerial photograph interpretation.

Laboratory Procedures

The laboratory procedures were the same as those from the earlier till surveys. Chemical analysis was performed at Bondar-Clegg Company Limited, Ottawa, using the methods outlined in Appendix A and for the 15 elements listed in Fig. 20.

3C. 1985-88 TILL SURVEY - SOUTH MOUNTAIN BATHOLITH

Introduction

During the period 1985 to 1989 a till mapping and geochemical sampling program was carried out over the South Mountain Batholith (Fig. 21). A total area of 10 000 km^2 was sampled at an average density of 1 per 6.0 km^2 (Fig. 21, Table 1). The aims of the survey were to map the distribution and provenance of surficial deposits overlying the batholith, and to sample till on a 2 km^2 grid to add to a database of regional geochemistry (Finck and Graves, 1985, 1986a, b; Graves *et al.*, 1987; Finck *et al.*, 1987a, b; 1988a, b; 1989a).

Mapping results have been published as a series of 1:50 000 scale maps of surficial geology, clast lithology and geochemistry (Finck and Graves, 1987a-d; Finck *et al.*, 1988c, 1989b-e; Graves and Finck, 1990). The survey has also generated a number of papers which interpret the relationship between the bedrock and till geochemistry (Boner *et al.*, 1987; Graves *et al.*, 1988; Graves and Finck, 1988).

Field Methodology

Before any field sampling commenced, an air photo interpretation was completed for the survey area to classify landform features (Graves *et al.*, 1988). The sampling program itself was planned with sites on a regular 2 km grid. Most access was by road, sea or helicopter in the more remote areas of southwestern Nova Scotia.

About 4 kg till samples were obtained by one of three means: (1) pits dug by hand with a crowbar and long-handled spade to depths of 0.5 to 1.0 m, (2) road cuts and (3) sea cliff exposures (Graves *et al.*, 1988). At each sample site the till was separated into its matrix and clast fractions by sieving with a -1.25 cm plastic (grizzly) screen to retain the pebbles.

Detailed field notes about the till samples were taken at each site and samples were subdivided using the physical attributes of colour, texture, composition, clast lithology, surface morphology and stratigraphic position (Graves and Finck, 1986). The survey identified four till facies units overlying the South Mountain Batholith (Graves and Finck, 1986).

Laboratory Procedures

At the Technical University of Nova Scotia till matrix samples were prepared for chemical analysis by wet sieving using -50+230 mesh (-300 + 62.5 μm) and -230 mesh (-62.5 μm) fractions. To promote the settling of particles, the silt and clay fractions (62.5 μm), the water and samples were allowed to stand for 24 to 48 hours. Heavy minerals from the -50+230 mesh (-300 + 62.5 μm) fraction were obtained as a concentrate using tetrabromoethane (SG 2.96). The analytical methods are summarized in Appendix A for the elements listed in Figure 21.

4. RATIONALE FOR REGIONAL BIOGEOCHEMICAL (PHYTOGEOCHEMICAL) SURVEYS

Most exploration geologists feel that Canada is covered with an over-abundance of shrubs and trees which impede mineral exploration. This view overlooks the fact that a biogeochemical survey can provide valuable geochemical information about the substrate not obtainable by sampling of other surficial materials. This is largely because trees and other plants, through their root systems, selectively extract the elements essential for their growth from soil, groundwater and bedrock. A large tree is capable of integrating, through its roots, the geochemical signature of many cubic metres of soil, bedrock and migrating groundwater. Biogeochemistry can therefore provide a 'window' through surficial deposits to the underlying bedrock to provide important and different geochemical data than those normally obtained from sampling other surficial media. Recent work at the Geological Survey of Canada (Dunn, 1988) has tested and established rapid, practical and cost-effective methods of vegetation sampling and analysis to assist the discovery of mineralization. Although processes in the biosphere are extremely complex, biogeochemistry can be a valuable and viable method for exploration (Dunn, 1988, 1989).

Many biogeochemical studies have reported metal uptake processes, metal distribution patterns among species, or seasonal fluctuations in chemistry. In Canada, reconnaissance level geochemical surveys

using soils and lake sediments have succeeded in outlining broad regional patterns of metal abundance and have led to the discovery of significant mineral deposits (Shacklette and Boerngen, 1984; Hornbrook, 1989). However, to date, few reconnaissance level biogeochemical studies have been conducted.

4A. 1987 BIOGEOCHEMICAL SURVEY - EASTERN MEGUMA TERRANE

The Nova Scotia study presents the first example of a regional biogeochemical survey for gold in Canada (Dunn *et al.*, 1989; Rogers and Dunn, 1989). Biogeochemical studies in Nova Scotia have focused mainly at the prospect scale (Brooks *et al.*, 1981, 1982; Miller, 1984; Rogers and Dunn, 1989; Dunn *et al.*, in press). At the Millet Brook U-Cu prospect Brooks *et al.* (1982) found that biogeochemistry detected U mineralization that otherwise has poor soil or till response. A comparative study at the Beaver Dam gold prospect (Rogers and Dunn, 1989; Dunn *et al.*, in press) also indicated an increased gold response in plant tissue when compared to soil or till sampling. Miller (1984) also reported an excellent response to gold mineralization using humus samples. Brooks *et al.* (1981) indicated a significant arsenic and antimony response in horsetails (*Equisetum*) growing over areas of gold mineralization.

Introduction

In June 1987 the regional survey pilot project (Dunn, 1988) sampled vegetation at 2 km intervals along all driveable roads and tracks covering a 5000 km^2 area of the eastern Meguma Terrane of Nova Scotia, extending from just west of Beaver Dam eastward to Canso (Fig. 22). A total of 854 locations were visited during a three week period, including detailed sampling at approximately 200 sites over zones of known or suspected mineralization at the Beaver Dam gold deposit (Rogers and Dunn, 1989; Dunn *et al.*, in press). The regional survey of about 600 sites had an average density of 1 per 8.43 km^2 and 1 per 46.73 km^2 for the balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*) species, respectively (Rogers and Dunn, 1989). The total cost of the survey, including collection, sample preparation and analysis, was about $30,000.

Results from the biogeochemical survey are published as a Geological Survey of Canada open file (Dunn *et al.*, 1989). The regional bark survey results are discussed by Dunn (1988). The regional twig survey data are discussed, along with the Beaver Dam detailed study, by Rogers and Dunn (1989) and Dunn *et al.* (in press).

Field Methodology

The survey was conducted along all available tracks by a two-man crew in four wheel drive trucks at a 2 km linear spacing. At each site samples of three species were taken in order to maximize the survey effectiveness. The most common species is balsam fir (*Abies balsamea*), which is known to accumulate gold in its twigs. Red spruce (*Picea rubens*) bark and shrub alder (*Alnus crispa*) twigs were also collected (Dunn *et al.*, 1989).

Spruce bark scale samples were obtained by scraping 30-50 g of material into a paper bag with a blunt knife. Obvious contaminants, such as loose moss and sap globules were excluded. The outer scales were selected since the inner bark is chemically different from the outer dead tissues. Strong enrichments of gold, arsenic and antimony are found in the outer bark (Dunn, 1988). Because of the relative rarity of this species, spruce bark outer scales could only be collected at approximately every fifth site, a sample density of approximately 1 per 47 km^2.

The chemistry of a twig varies along its length so in order to smooth out differences twigs of similar diameter were collected (Dunn *et al.*, 1989). The last five to seven years' growth of balsam fir and the last three years' growth of alder twigs were collected at least 50 m away from roads to minimize possible contamination. All samples were air dried in the field. At the base camp the samples were dried for 15 minutes in a microwave oven. At each site, details of the area were noted on a computer coding sheet to aid in later data interpretation (Dunn *et al.*, 1989). At Beaver Dam the same sample location grid and spacing were used as in the previous soil and till assessment surveys at the Mill Shaft area (Dunn *et al.*, in press).

Laboratory Procedures

The needles were separated from twiggy material, which was then cleaned and macerated. The fir needles were stored for later reference. Twigs were placed in aluminum trays and ashed at 470°C in a muffle furnace. Ashing was done to concentrate the trace metals of interest prior to analysis. The ashing yielded about 0.5 to 1.0 g of sample. No correction for variation in ash yield was made. The samples were analysed by Induced Neutron Activation Analysis (Appendix 1) for the elements given in Figure 22.

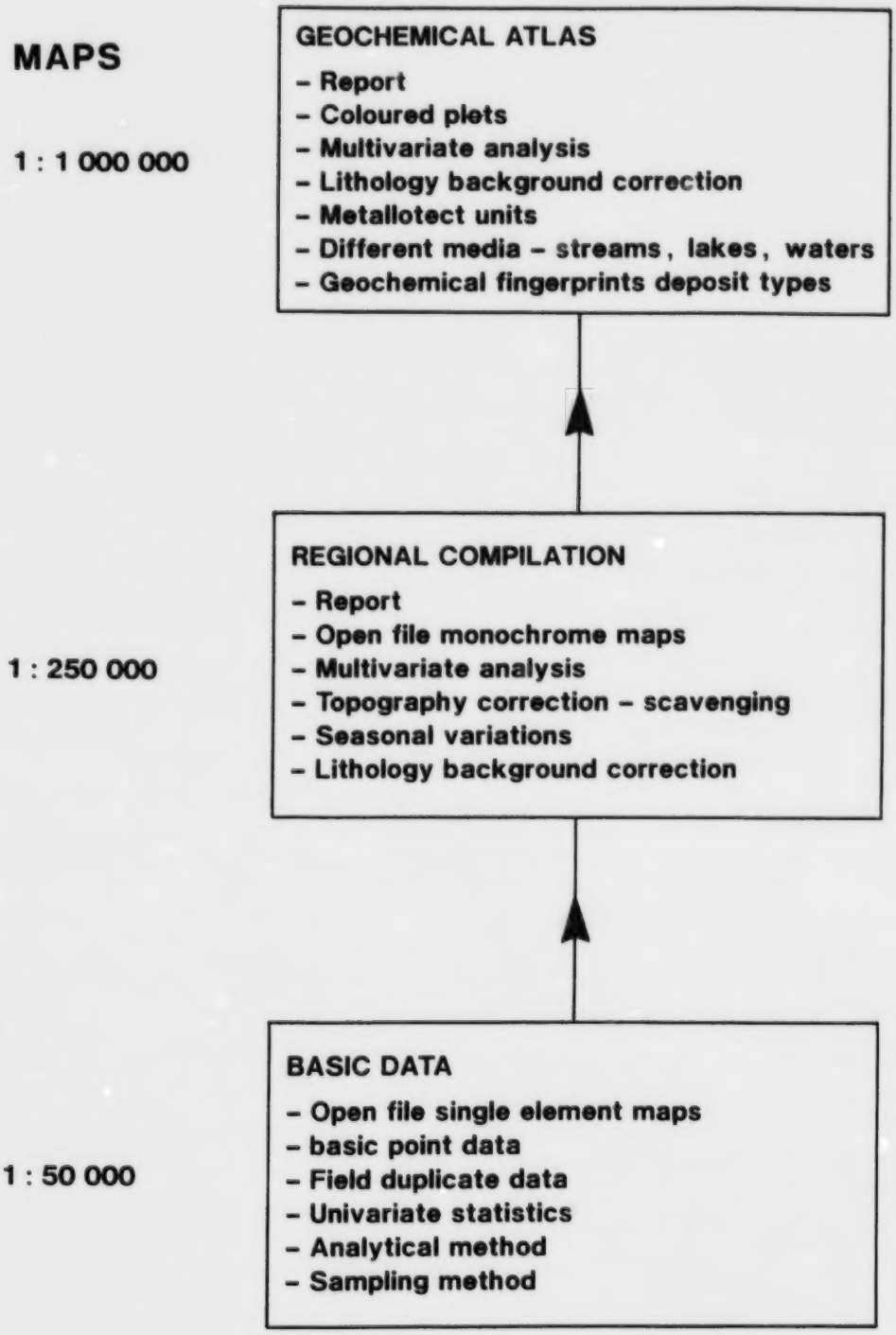


Figure 1. Data presentation and reduction methods for regional geochemical data (after Rogers, 1984).

Figure 2. Physiography of Nova Scotia (after Roland, 1982).

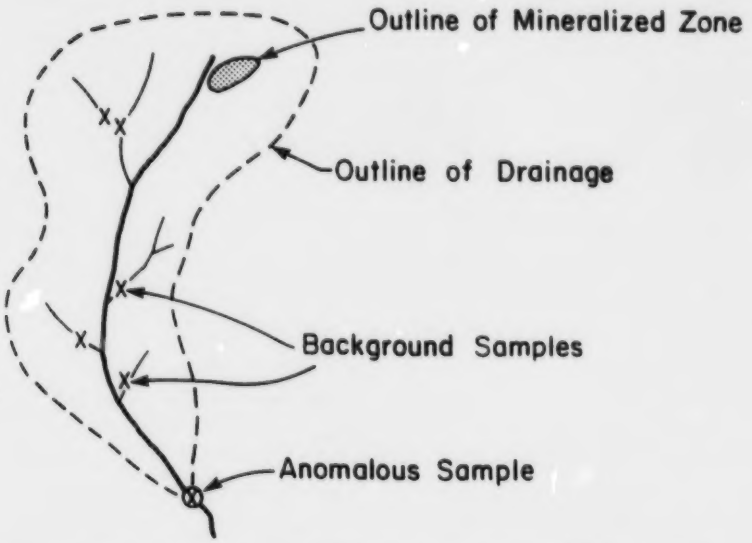


Figure 3. Catchment basin model for stream sediments (after Hawkes, 1976).

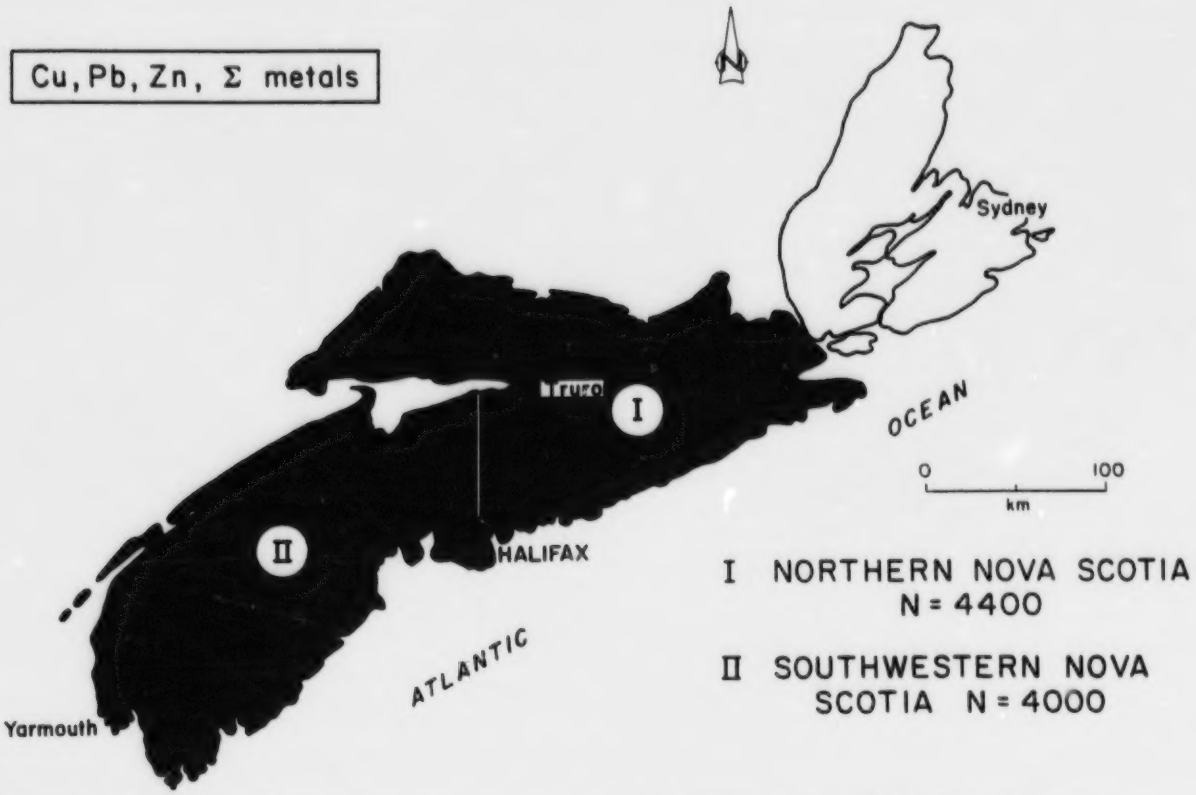


Figure 4. Stage 1 regional stream sediment surveys (1957-1958), mainland Nova Scotia, with area covered, samples taken and elements analyzed.

Area	Cu	Pb	Zn	Ag	Fe	Mn	As	Mo	U	Cd	Ba	F	Sr	Ni	Hg	Co
I	X	X	X		X	X	X	X	X						X	
II	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
III	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

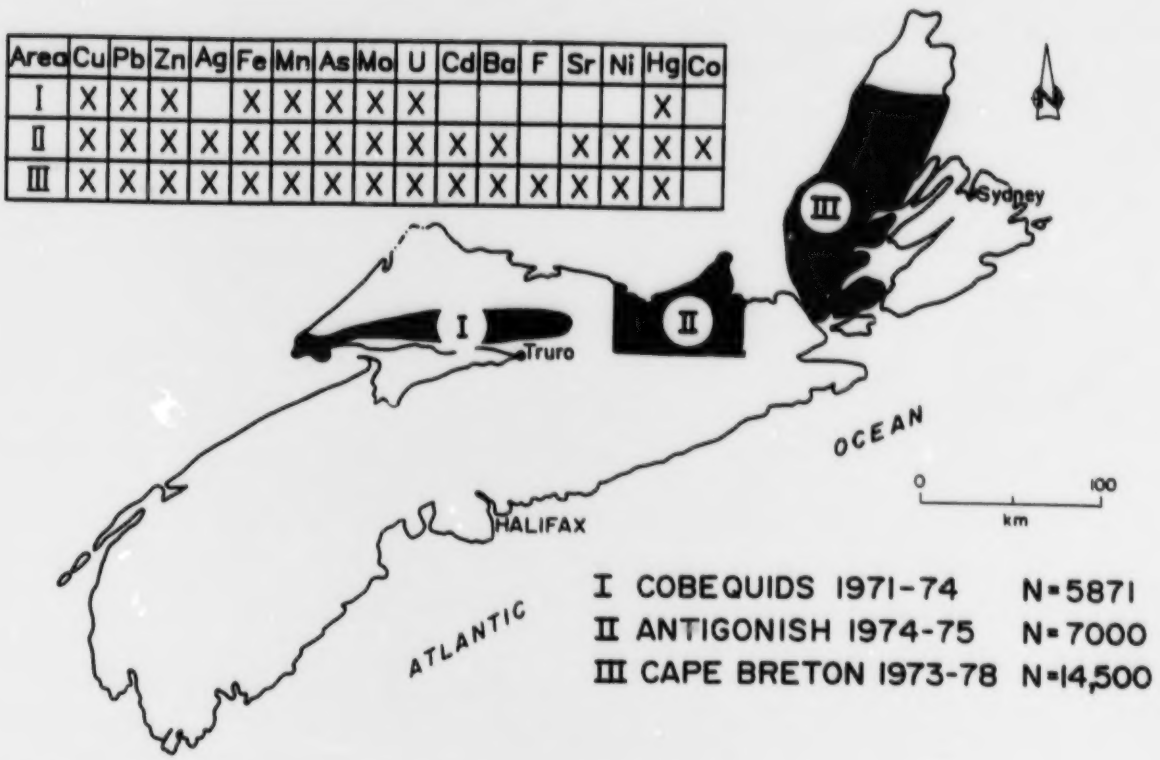


Figure 5. Stage 2 regional stream sediment surveys (1971-1978) in highland areas of Nova Scotia with area covered, samples taken and elements analyzed.

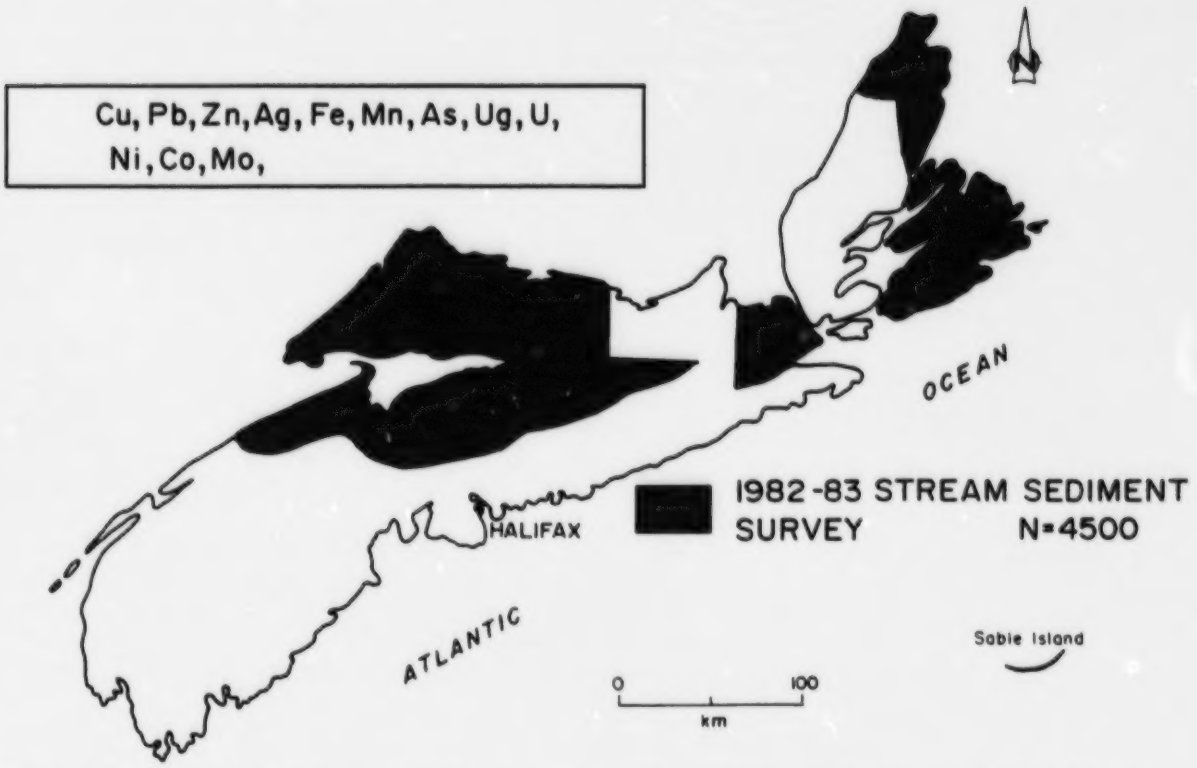


Figure 6. Stage 2 regional stream sediment surveys (1982-1983) in northern Nova Scotia with area covered, samples taken and elements analyzed.

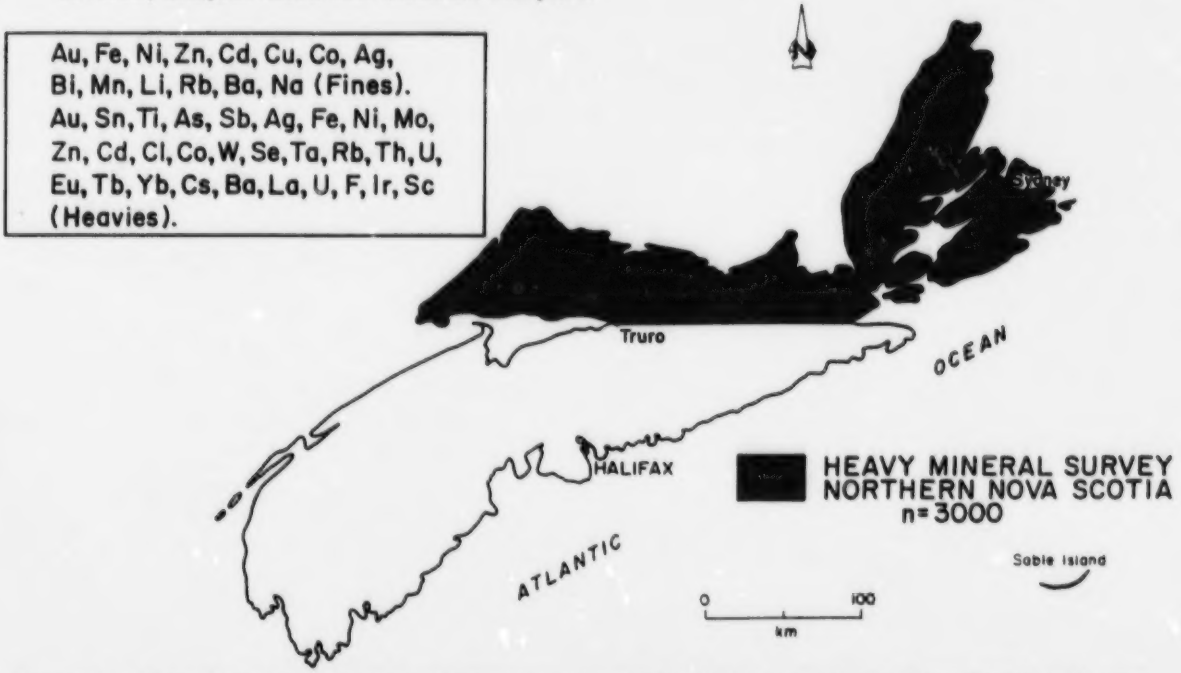


Figure 7. Stage 3 regional stream sediment surveys (1986-1987) in northern Nova Scotia with area covered, samples taken and elements analyzed.

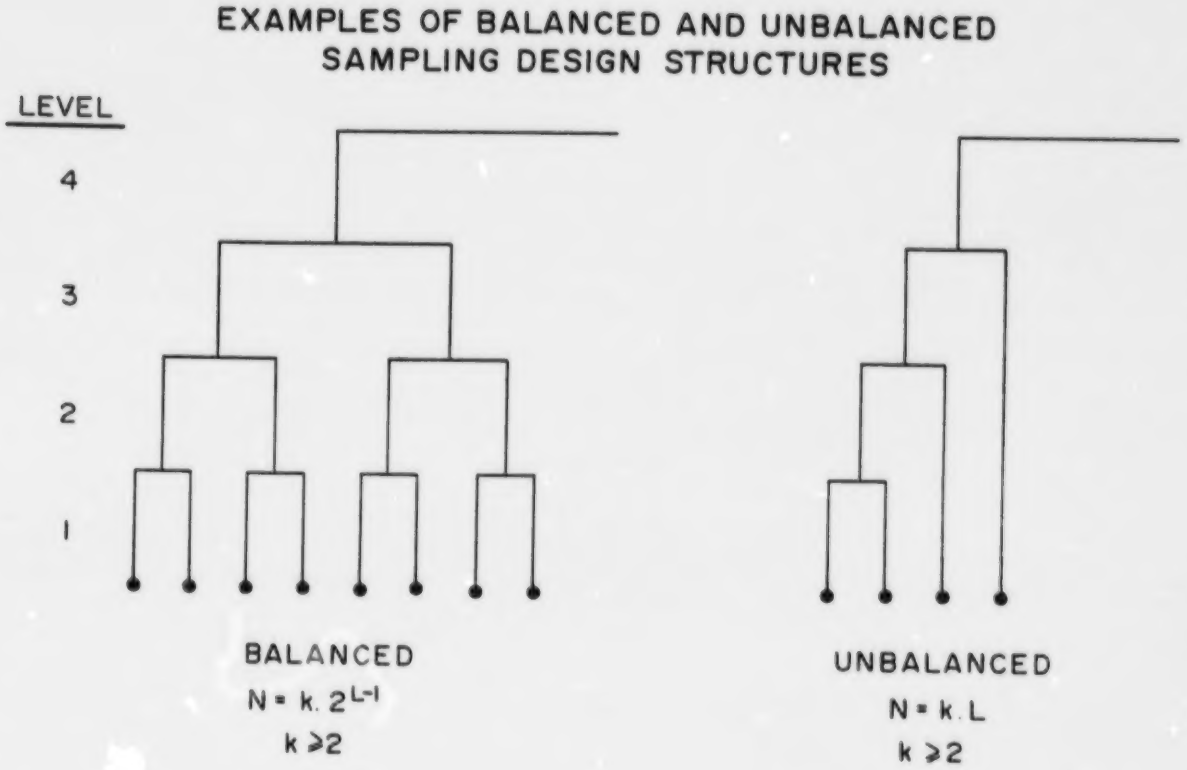


Figure 8. Illustration of balanced and unbalanced sampling designs (after Garrett *et al.*, 1980).

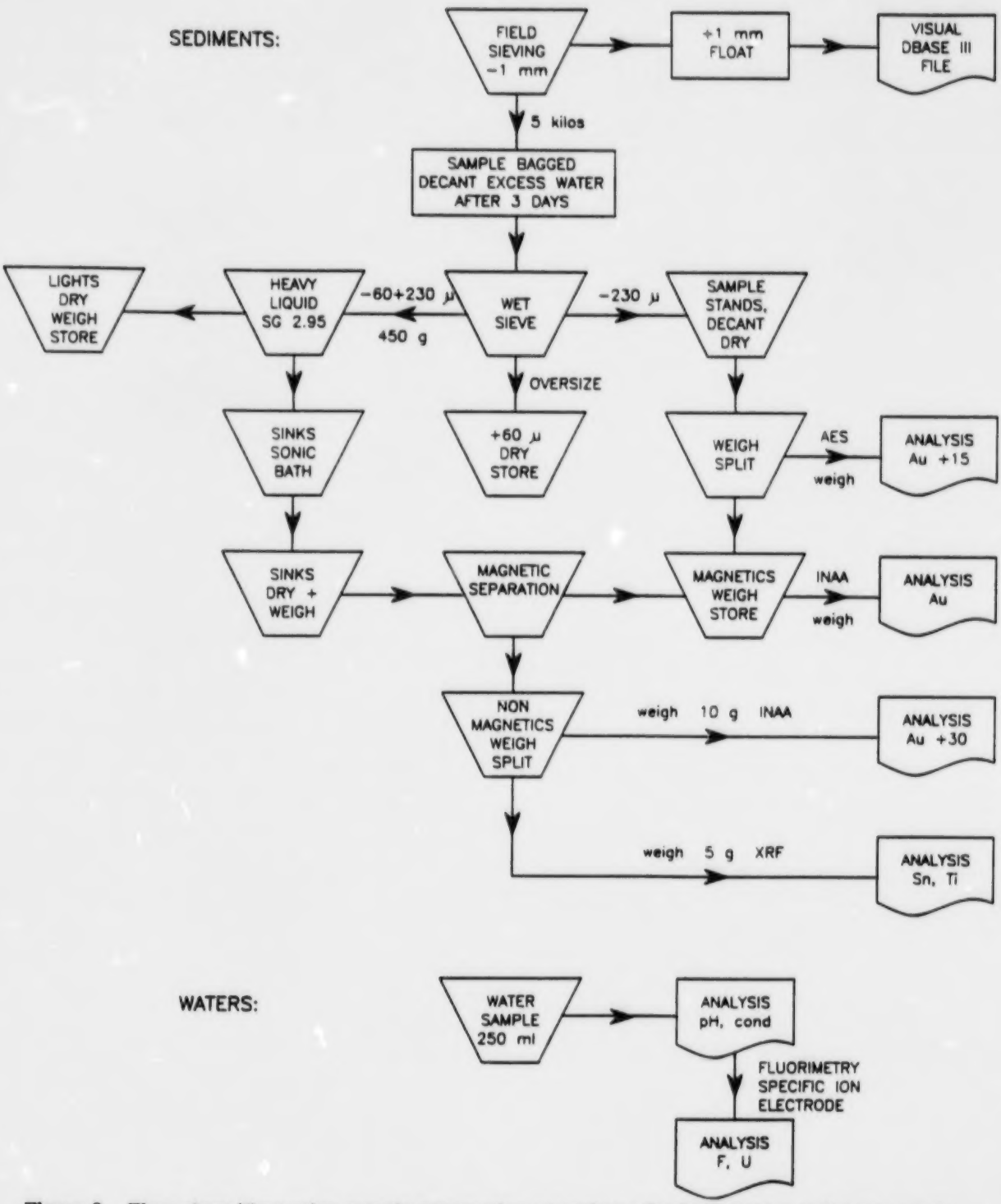


Figure 9. Flow chart illustrating sample preparation procedures for bulk stream sediment samples (Mills, 1989).

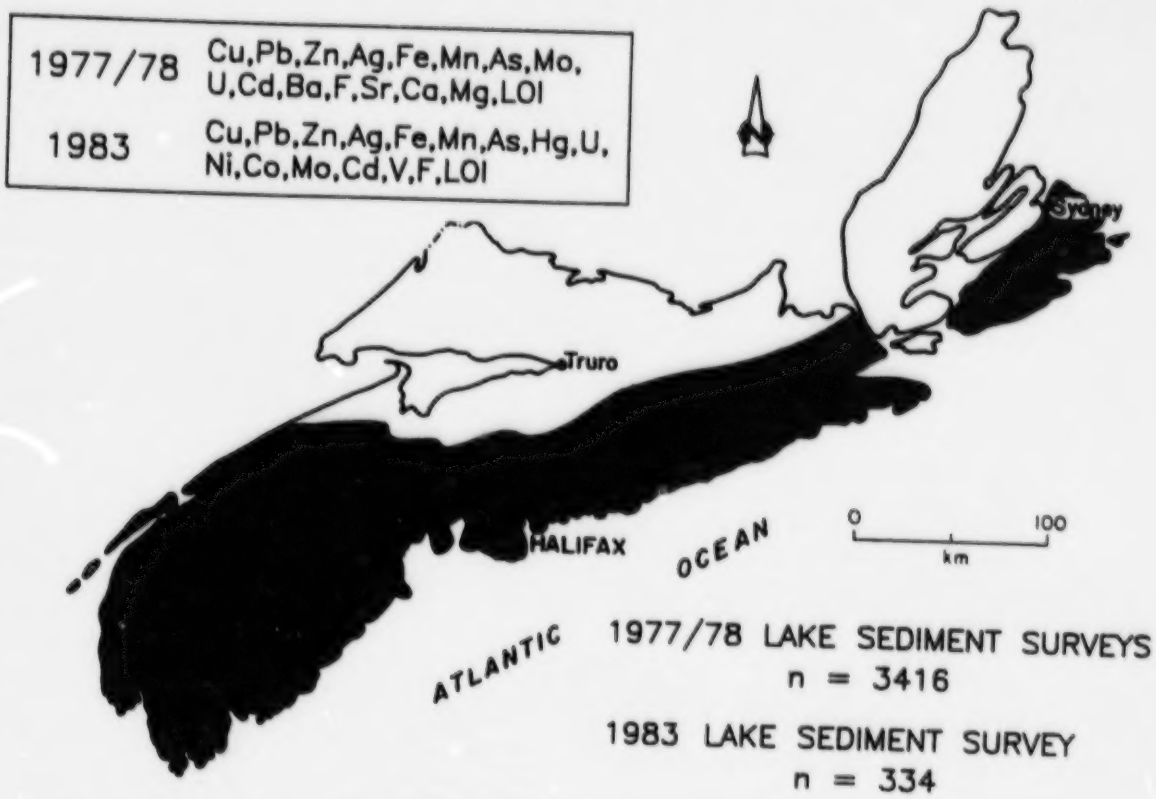


Figure 10. Regional lake sediment survey (1977-1978) in southwestern Nova Scotia with area covered, samples taken and elements analyzed.

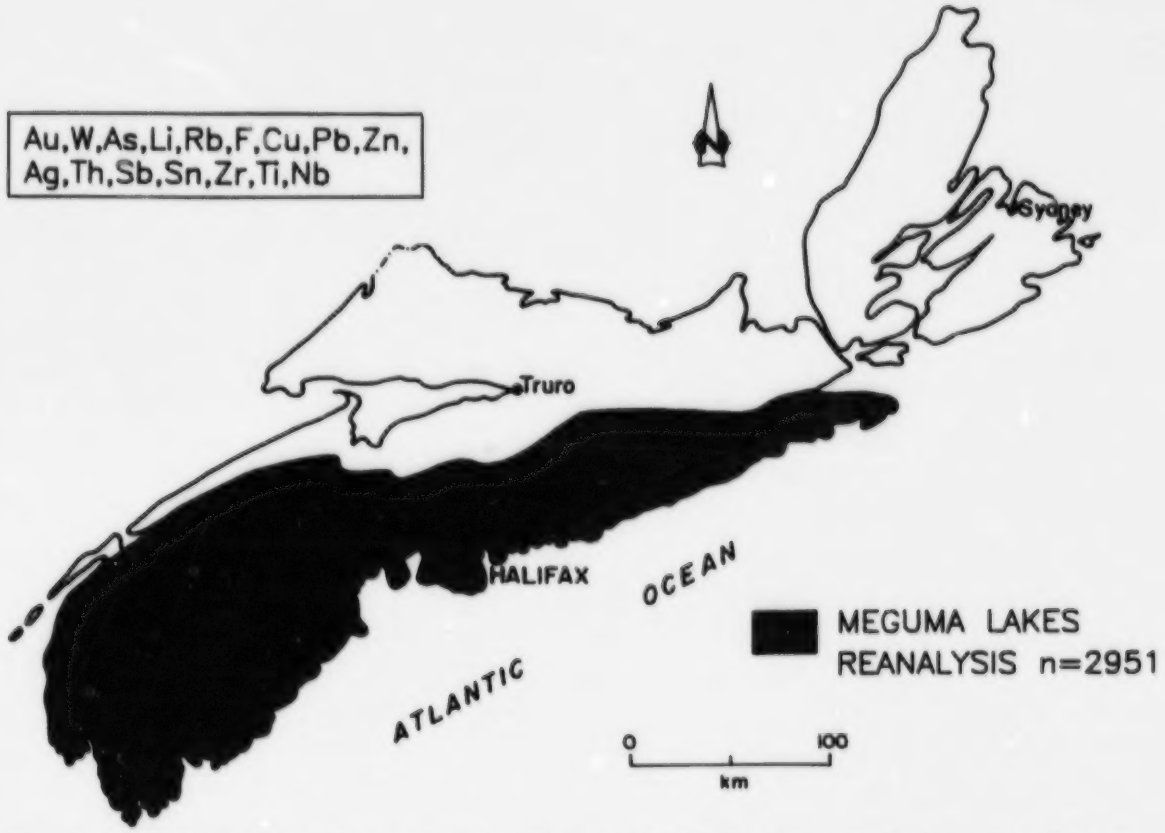


Figure 11. Regional lake sediment survey, 1984 re-analysis of selected archived samples from the 1977 to 1978 survey, including details of area covered, samples taken and elements analyzed.

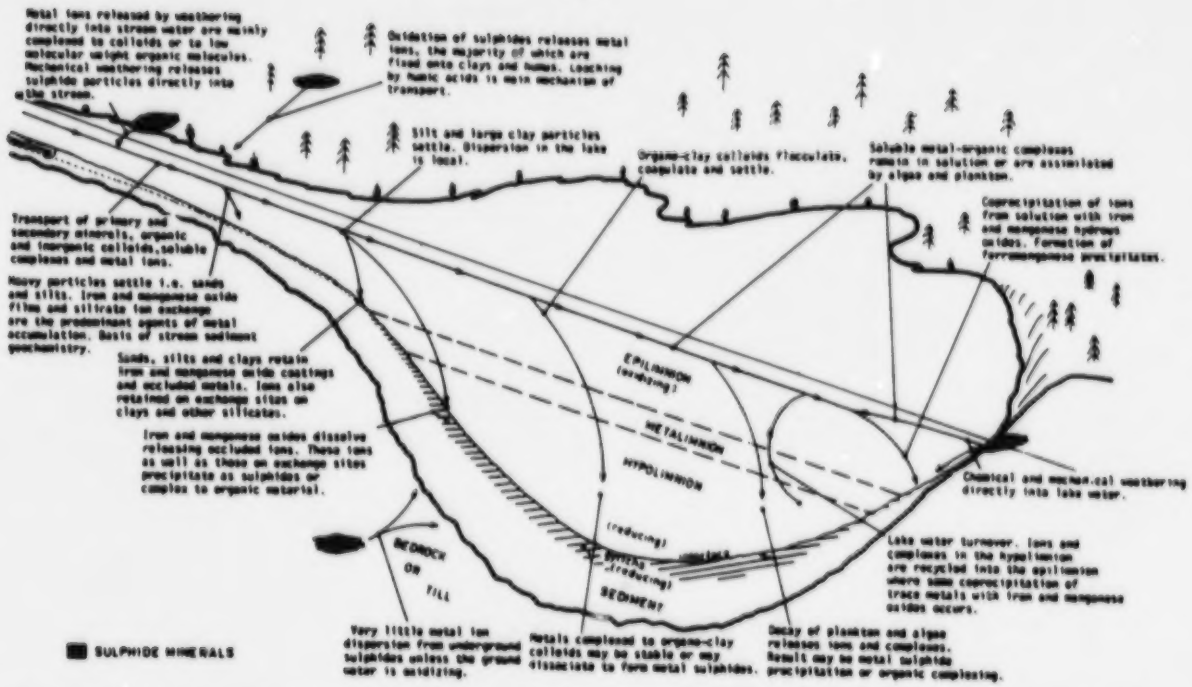

Metal ions released by weathering directly into stream water are mainly complexed to colloids or to low molecular weight organic molecules. Mechanical weathering releases sulphide particles directly into the stream.
Oxidation of sulphides releases metal ions, the majority of which are fixed onto clays and humus. Leaching by humic acids is main mechanism of transport.
Silt and large clay particles settle. Dispersion in the lake is local.
Organo-clay colloids flocculate, coagulate and settle.
Soluble metal-organic complexes remain in solution or are assimilated by algae and plankton.
Coprecipitation of ions from solution with iron and manganese hydrous oxides. Formation of ferromanganese precipitates.
Transport of primary and secondary minerals, organic and inorganic colloids, soluble complexes and metal ions.
Heavy particles settle i.e. sands and silts. Iron and manganese oxide films and silicate ion exchange are the predominant agents of metal accumulation. Basis of stream sediment geochemistry.
Sands, silts and clays retain iron and manganese oxide coatings and occluded metals. Ions also retained on exchange sites on clays and other silicates.
Iron and manganese oxides dissolve releasing occluded ions. These ions as well as those on exchange sites precipitate as sulphides or complex to organic material.
EPILIMNION (oxidizing)
METALIMNION
HYPOLIMNION
(reducing)
BEDROCK OR TILL
SEDIMENT
Chemical and mechanical weathering directly into lake water.
Lake water turnover. Ions and complexes in the hypolimnion are recycled into the epilimnion where some coprecipitation of trace metals with iron and manganese oxides occurs.
SULPHIDE MINERALS
Very little metal ion dispersion from underground sulphides unless the ground water is oxidizing.
Metals complexed to organo-clay colloids may be stable or may dissociate to form metal sulphides.
Decay of plankton and algae releases ions and complexes. Result may be metal sulphide precipitation or organic complexing.

Figure 12. Lake sediment model for lakes of the Canadian Shield, from Timperley and Allan (1974).

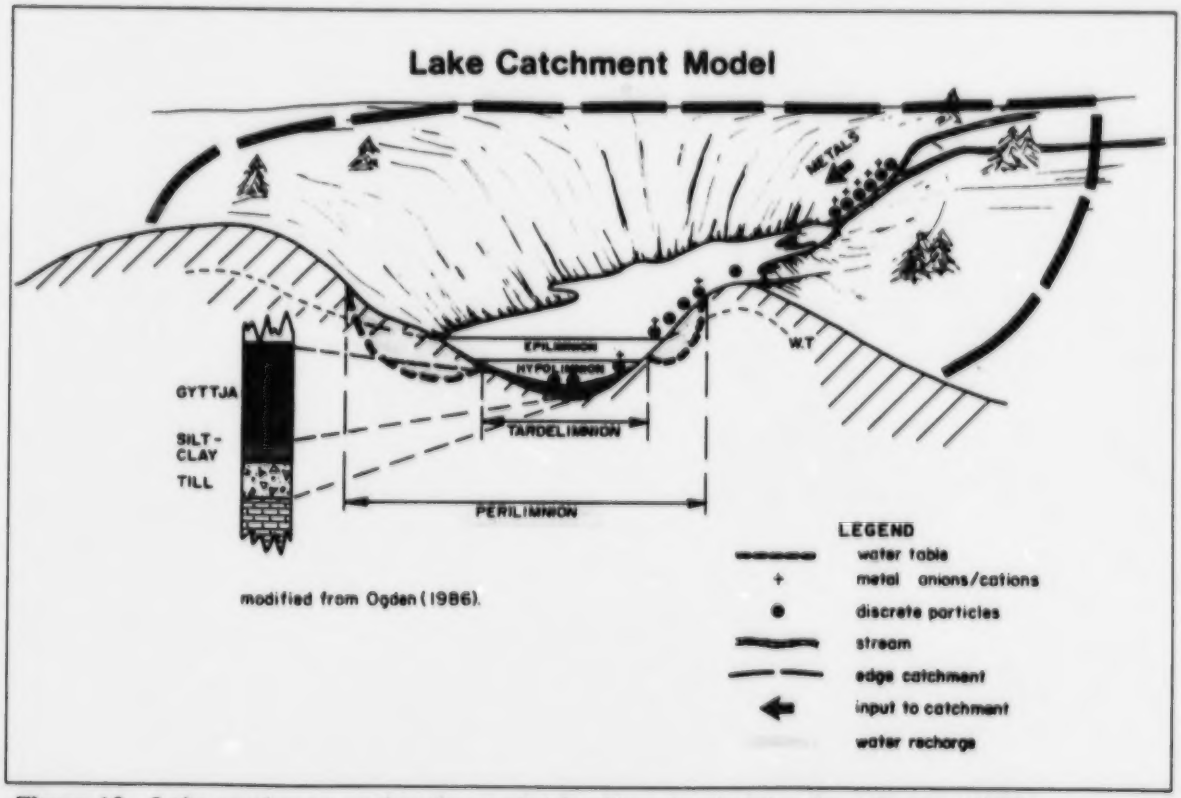
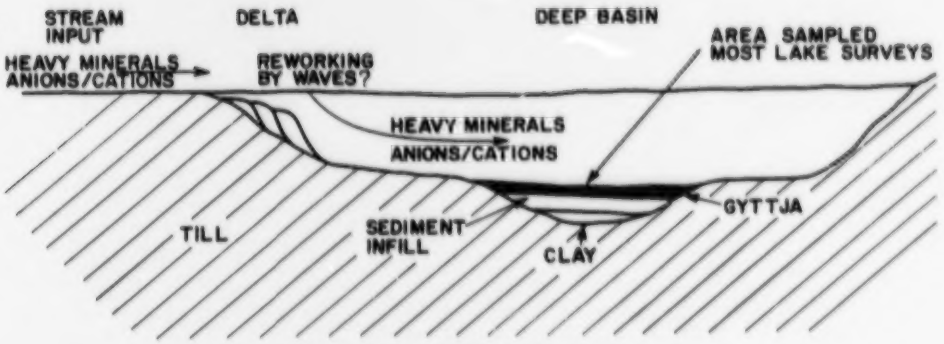


Figure 13. Lake catchment exploration model for Nova Scotia lakes from Rogers (1988).

A.



B.

HEAVY MINERAL PROVENANCE

SPECIES	S. G.	LONG LAKE	FIVE BRIDGE	LOWER TROUT LAKE	SLOANE'S LAKE
SPHALERITE	3.9 to 4.1				●
CHROMITE	4.1 to 4.9		▒		
RUTILE	4.2	▒			
BARITE	4.3 to 4.6	▒	▒	▒	●
ILMENITE	4.5 to 5.0	▒			
HOSCHILDITE	4.5			▒	●
ZIRCON	4.7	▒		▒	
MOLYBDENITE	4.7 to 4.8		▒		
PYRITE	4.9 to 5.1				●
MONAZITE	4.9 to 5.3	▒	▒	▒	●
MAGNETITE	5.2		▒		●
ZINCITE	5.4 to 5.7		▒	▒	
FE SILICATE	5.5 to 6.0	▒	▒		●
CUPRITE	5.8 to 6.2				●
ARSENOPYRITE	5.9 to 6.1				●
SCHEELITE	5.9 to 6.1	▒		▒	●
CASSITERITE	6.8 to 7.1	▒	▒	▒	●
HERZENBERGITE	6.8 to 7.1				●
GALENA	7.4 to 7.6				●
NATIVE SILVER	10.1 to 11.1	▒		▒	
NATIVE GOLD	12.0 to 20.0				●

▒ MEGUMA METASEDIMENTS ▒ GRANITOIDS

Figure 14. Diagram illustrating the capture of heavy minerals into lake sediments as the lake basin acts as a geochemical sink, and table comparing the mineral phases identified from 50 kg bulk samples of selected Meguma Zone lakes (from Rogers, 1988).

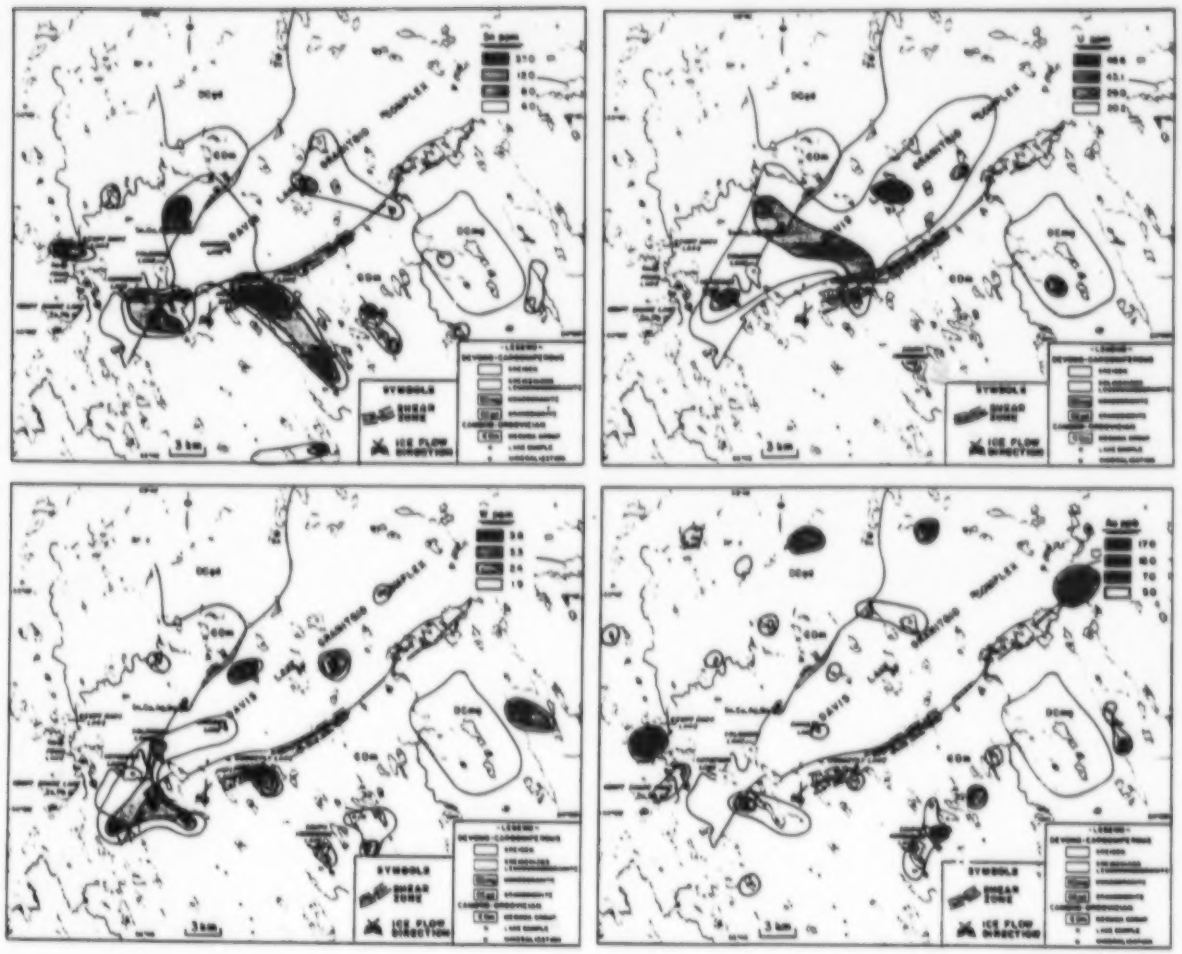


Figure 15. Lake sediment geochemical dispersion patterns around the East Kemptville deposit, southwestern Nova Scotia, for (a) tin (b) uranium (c) tungsten and (d) gold (from Rogers, 1987).

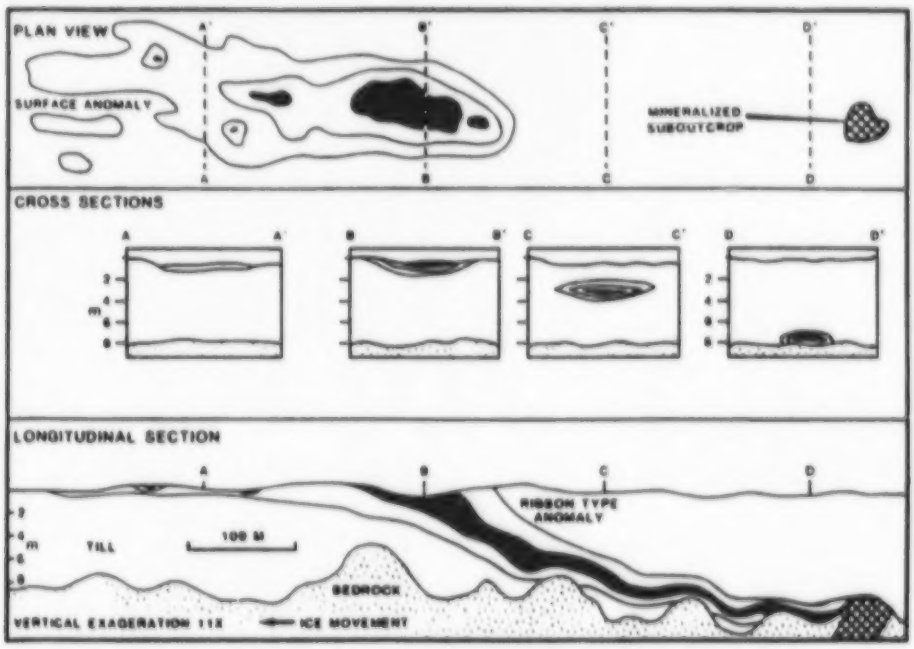


Figure 16. An idealized glacial dispersal model from Miller (1984).

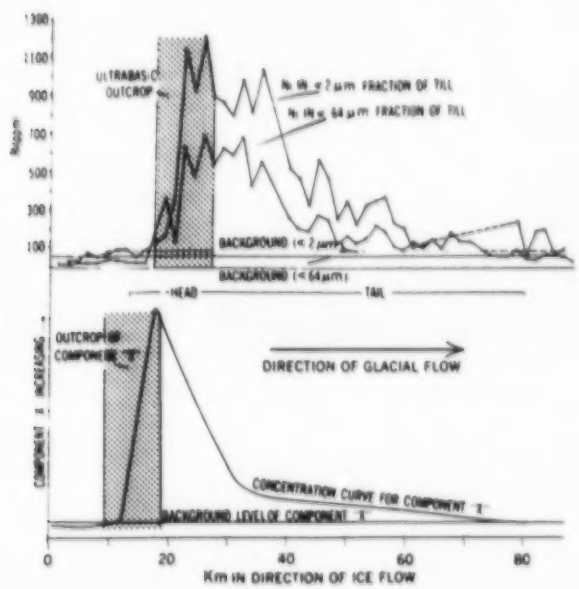


Figure 17. Dispersal curves for nickel in till, Thetford Mines area, Quebec. Actual (top) and idealized (bottom) curves show the relationship of the head and tail of a negative exponential curve (after Shilts, 1975).

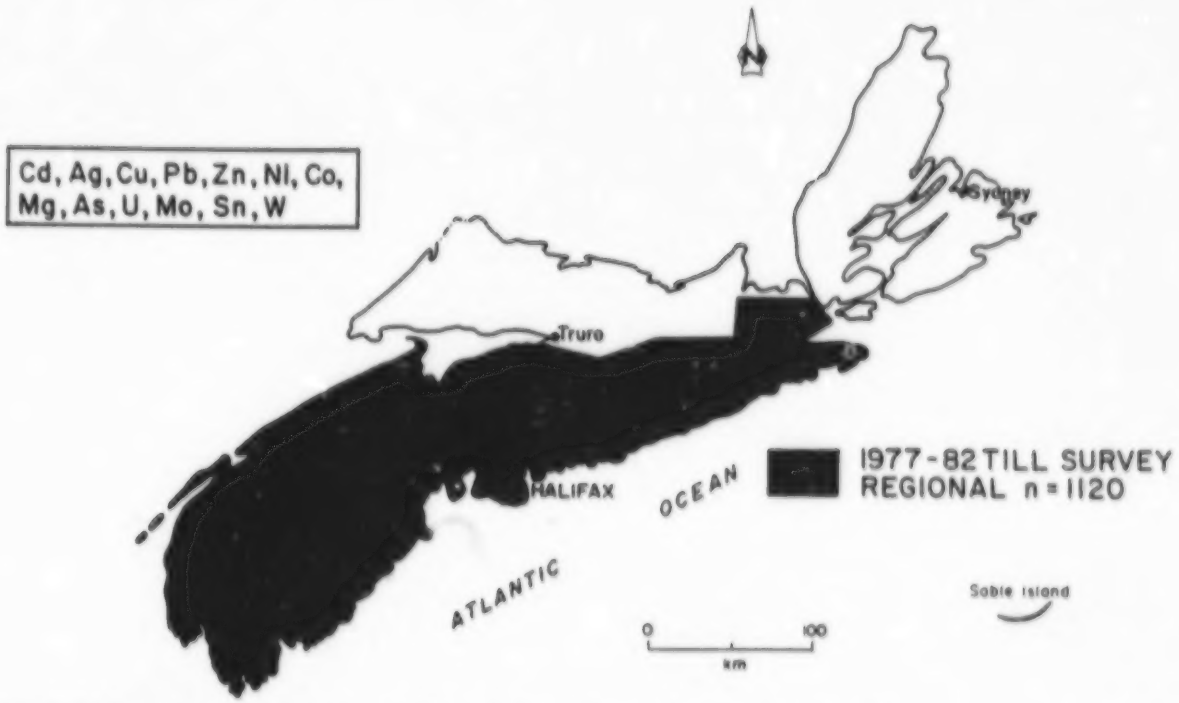


Figure 18. Regional till surveys (1977-1982), southwestern Nova Scotia, with area covered, samples taken and elements analyzed.

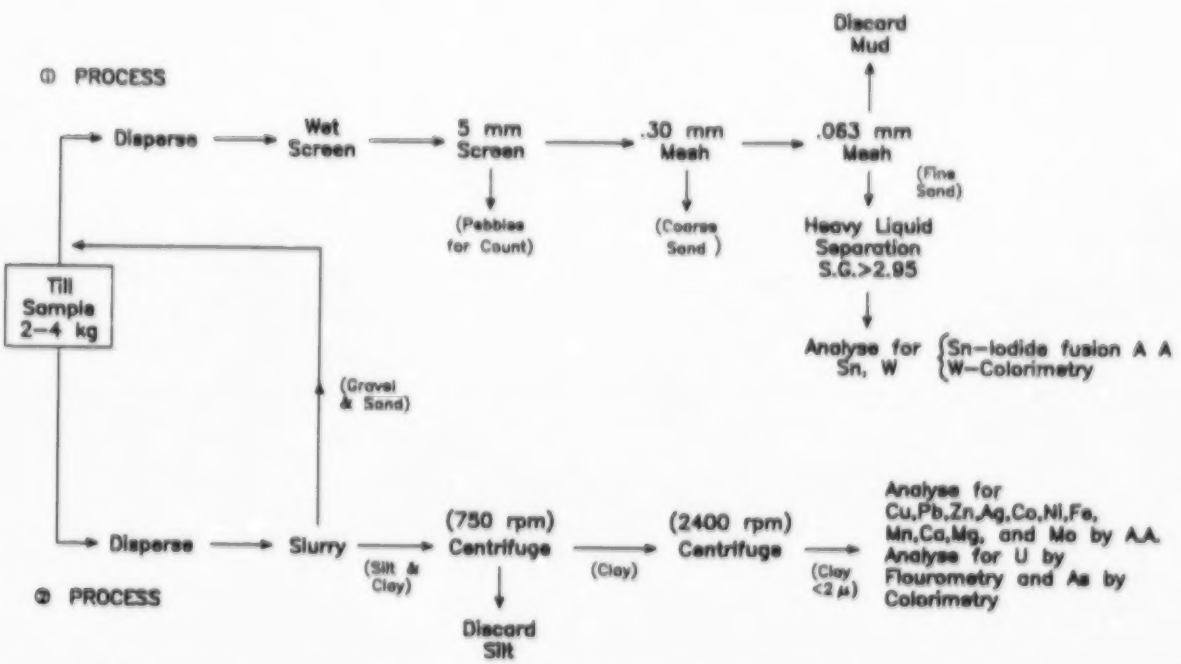


Figure 19. Flow chart illustrating sample preparation and analytical procedures for till samples (from Stea and Finck, 1984).

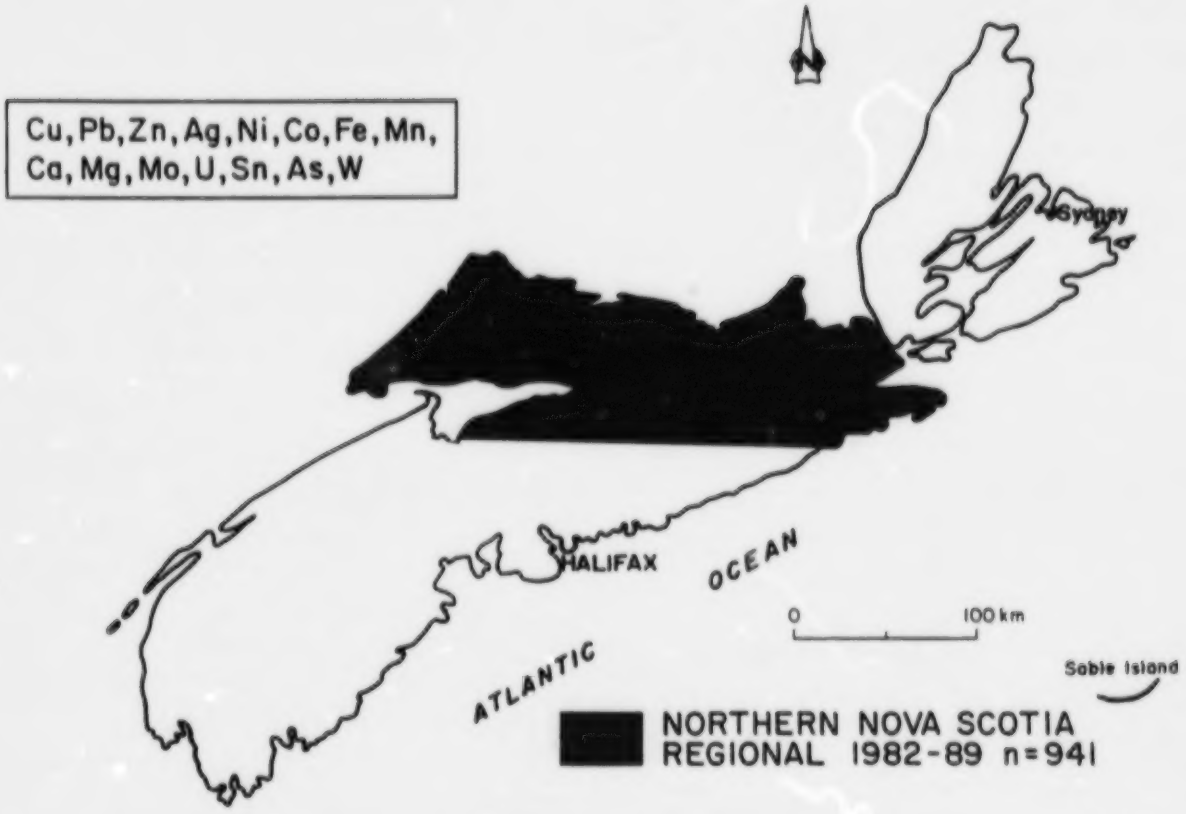


Figure 20. Regional till surveys (1982-1989), northern Nova Scotia, with area covered, samples taken and elements analyzed.

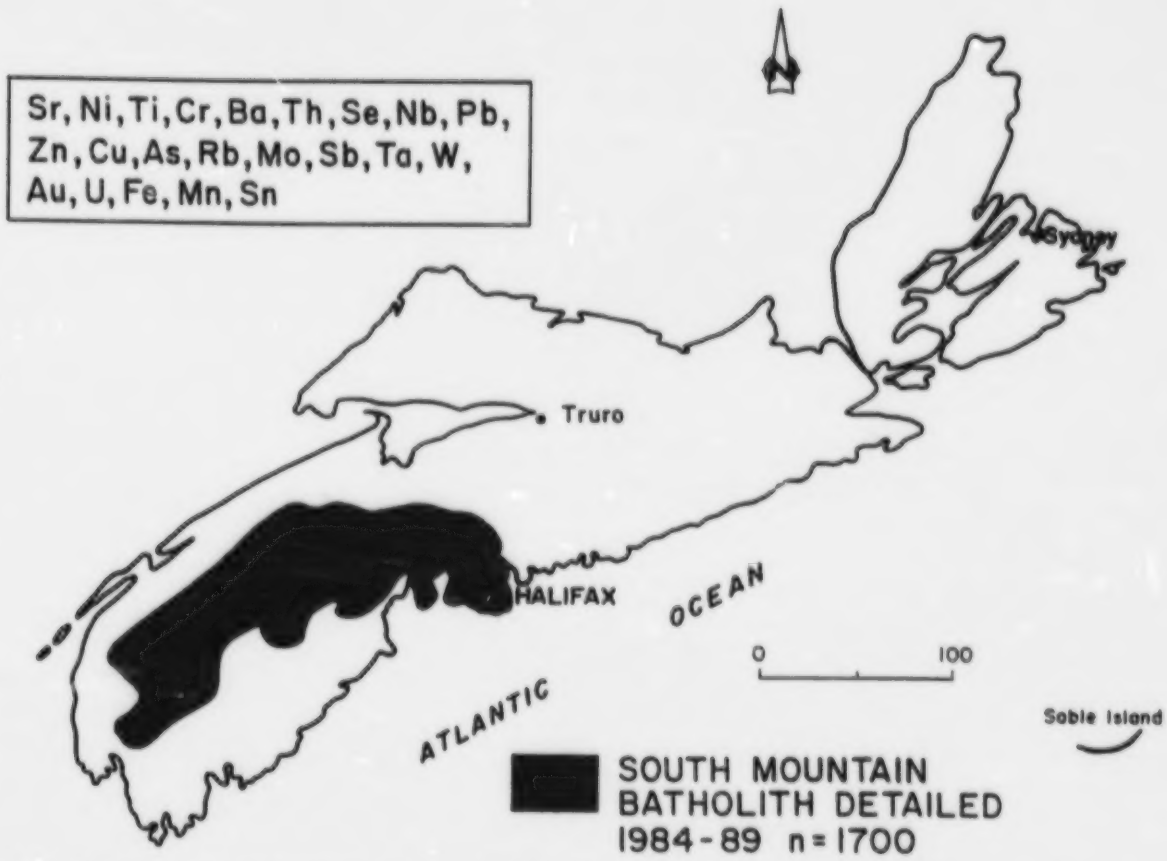


Figure 21. Detailed regional till surveys (1984-1989), South Mountain Batholith Project, with area covered, samples taken and elements analyzed.

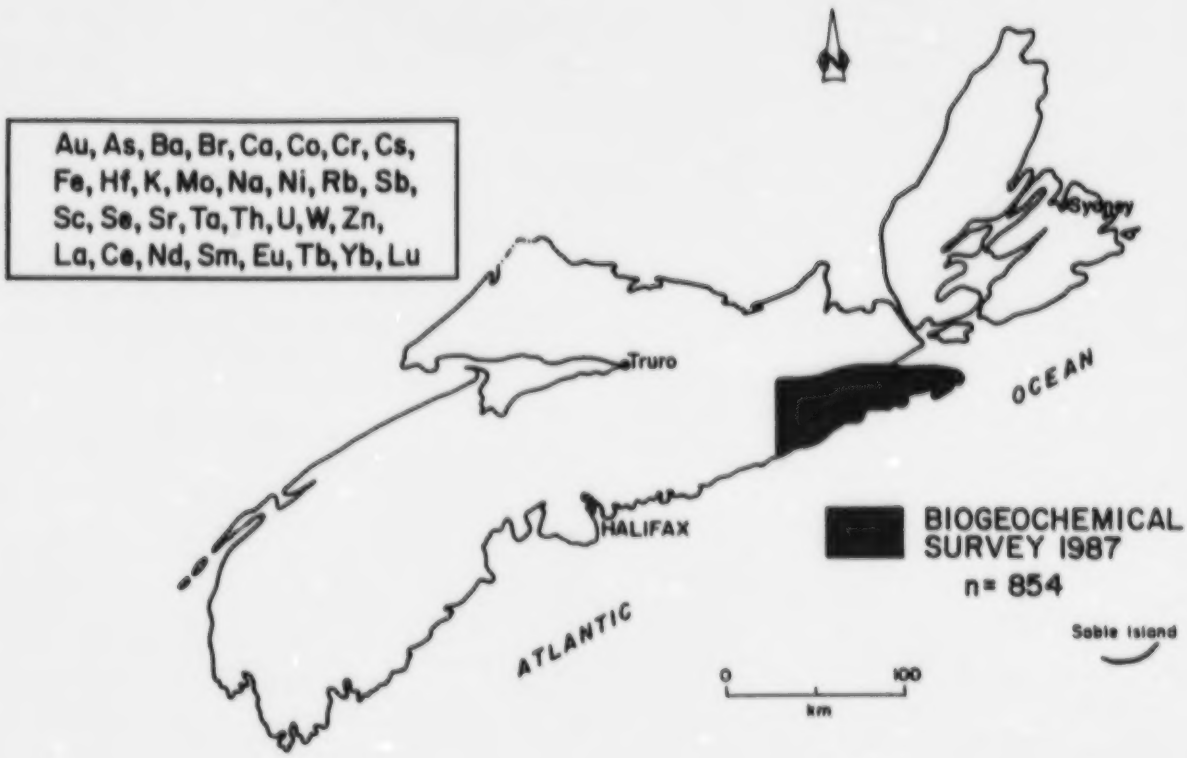


Figure 22. Regional biogeochemical survey (1987), eastern Nova Scotia, with area covered, samples taken and elements analyzed.

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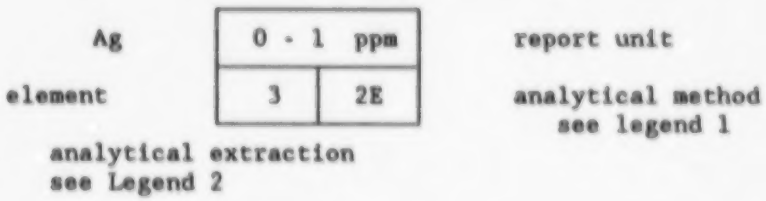
APPENDIX A:

SUMMARY OF ANALTYICAL METHODS FOR REGIONAL GEOCHEMICAL SURVEYS

EXPLANATION OF SUMMARY SHEETS

For each survey type and element analyzed, a box is listed with details of detection limit, unit of measurement, analytical method and extraction, as illustrated in the following example:



When blank there was no analysis performed

LEGEND 1: ANALYTICAL METHODS

1. NEUTRON ACTIVATION = N.A. / = I.N.A.A. — NEUTRON ACTIVATION / INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS
2. ATOMIC ABSORPTION = A.A. / = A.A.S. — ATOMIC ABSORPTION SPECTROSCOPY
   (a) flameless aas
   (b) hydride aas
   (c) spectrophotometer
   (d) mercury analyzer
   (e) spectroscopy
   (f) air-acetylene
3. X-RAY DIFFRACTION = X.R.D.
4. ATOMIC EMMISION SPECTROSCOPY = A.E.S.
5. DIRECT COUPLED PLASMA = D.C.P.
6. FIRE ASSAY
7. INDUCTIVELY COUPLED PLASMA = ICP
8. FLUORIMETRY (TURNER FLUOROMETER)
9. NITROUS OXIDE/ACETYLENE
10. COLORIMETRICS
    (a) gutzeit
    (b) spectrophotometry
    (c) ag DDC
11. DIRECT ABSORPTION
12. pH METER
13. FLUORIMETRY
14. SPECIFIC ION ELECTRODE
15. pH METER WITH FLUORIDE-SENSITIVE ELECTRODE
16. EMMISION SPECTROGRAPH AND DENSIOMETER
17. X-RAY FLUORESENCE = XRF

LEGEND 2: EXTRACTION AND DIGESTION METHODS

1. BORATE FUSION
2. HF-$HC10_4$-$HN0_3$-HCl
3. Hot $HN0_3$-HCl
4. HCl-$HN0_3$ AQUA REGIA SOLUTION
5. $HN0_3$ (NITRIC LEACH)
6. HCl 6M LEACH
7. NaOH
8. $Na_2 CO_3$
9. HOT HCl-HNO_3 MIXTURE
10. NITRIC-PERCHLORIC (HNO_3-$HC10_4$)
11. AMMONIUM IODIDE AND HYDROCHLORIC ACID LEACH
12. CARBONATE FLUX FUSION AND HOT WATER LEACH
13. PELLET
14. $LiBO_2$-HCl FUSION
15. KOH FUSION

DRAINAGE SURVEYS : STREAM SEDIMENTS

Ag	Al	As	Au	Ba	Bi	Br	Cd	Ce	Co	Cu	Cr
.5 ppm	ppm	1. ppm	5. ppb	100 ppm	ppm	1. ppm	10. ppm	10. ppm	10. ppm	ppm	50. ppm
4 1	2 5	4 1	4/- 1/6	4 1	2 5	4 1	2 5	4 1	4 1	2 5	4 1
5. ppm	10. ppm	2. ppm	5/1. ppm	100 ppm	2. ppm	1. ppm	1. ppm	3. ppm	5. ppm	1. ppm	10. ppm
4 1	2 5	4 1	6/1	4 1	2 5	4 1	2 5	4 1	4 1	2 5	4 1
0.5 ppm	10. ppm	1. ppm	5. ppm	1. ppm	0.1 ppm		1. ppm	0.5 ppm		0.5 ppm	
5 2	2 5	3 2	4 1	2 5 7	2 5 7		2 5	2 5		2 5	
0.2 ppm	10. ppm	2. ppm		1. ppm					2. ppm	2. ppm	
0.1 ppm		2B 6A 2B		13 1.					3 2	1. ppm	
2C		10C								2C	

Cs	Eu	F	Fe	Hf	Hg	Ir	K	La	Li	Lu	Mn
1. ppm	ppm	ppm	0.5 %	2. ppm	ppm	100 ppm	ppm	5. ppm	ppm	0.5 ppm	ppm
4 1	4 1			4 1 4 1		4 1		4 1		4 1	
2. ppm	0.2 ppm	ppm	0.02 %	1. ppm	ppm	50 ppm	ppm	1. ppm	ppm	.05 ppm	ppm
4 1	4 1		0.1 %	4 1		4 1	10. ppm	4 1	1. ppm	4 1	1. ppm
2. ppm	ppm	ppm	2. ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
2 5	2 2		5 3		5. ppm		2 5		2 5		2 5
0.2 %	5. ppm	0.5 ppm	2F 6	.02 ppm	2A 3		2. ppm		1. ppm		2. ppm
0.1 %	02 ppm	6B 16	2C 4				5 2				5 2
%	ppm	ppm	2				ppm		ppm		5. ppm
											6 2
											.1 ppm
											4 2C

1987 Heavies

1986 Heavies

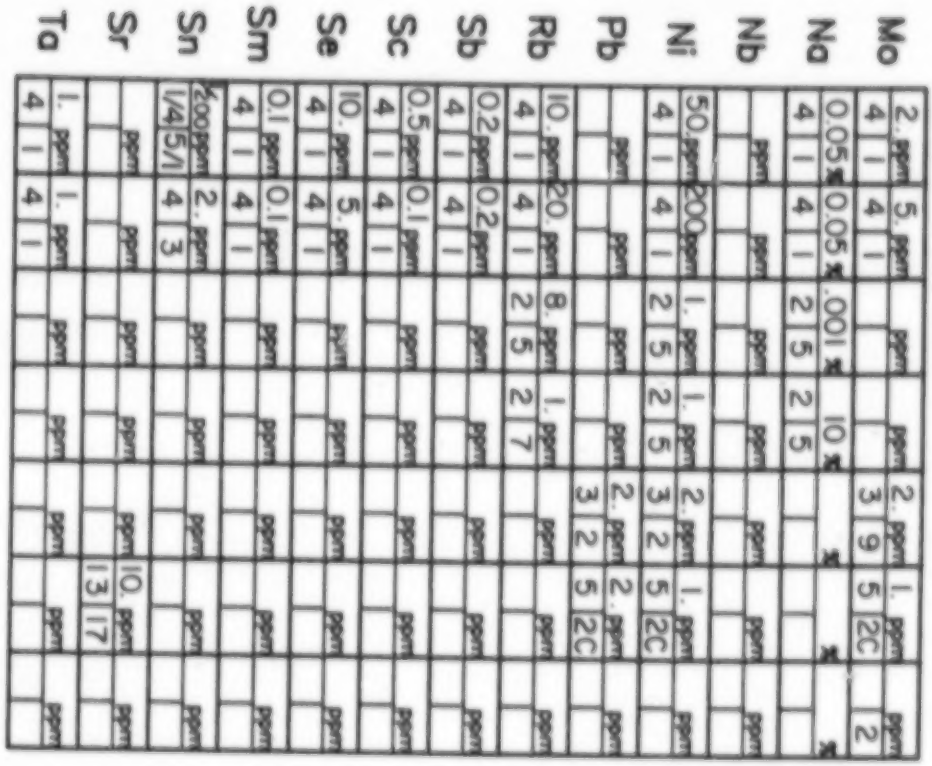
1987 Fines

1986 Fines

1982–83 Fines

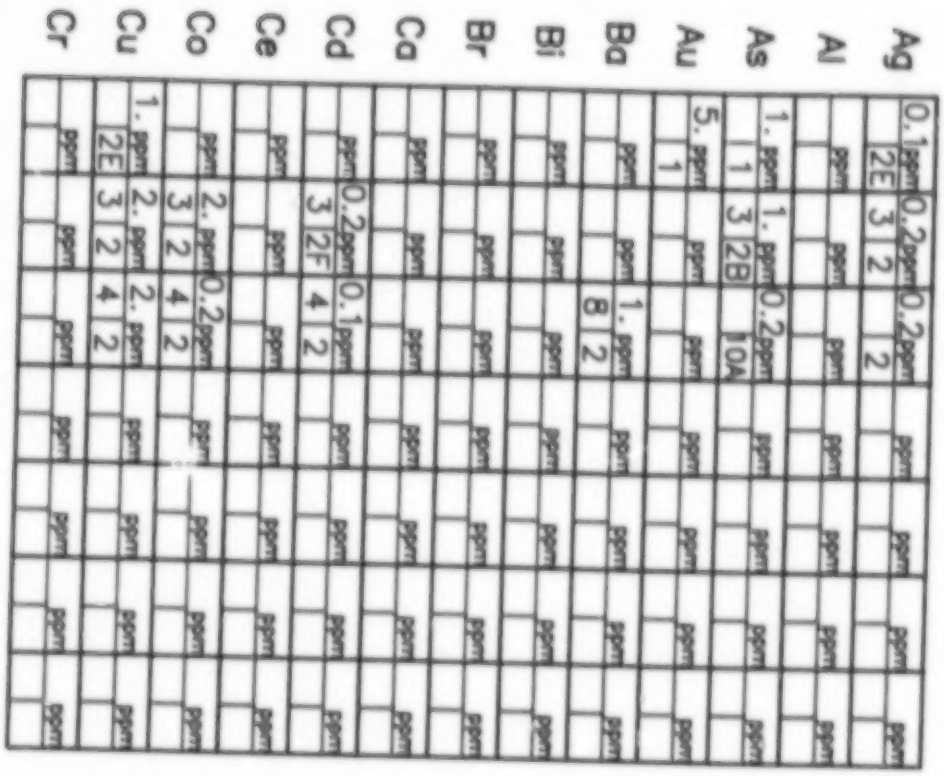
1973–77 N.N.S

1971–73


Mo
Na
Nb
Ni
Pb
Rb
Sb
Sc
Se
Sm
Sn
Sr
Ta
1987 Heavies
1986 Heavies
1987 Fines
1986 Fines
1982–83 Fines
1973–77 N.N.S.
1971–73

Tb
Te
Th
Ti
U
V
W
Yb
Zn
Zr
1987 Heavies
1986 Heavies
1987 Fines
1986 Fines
1982–83 Fines
1973–77 N.N.S.
1971–73

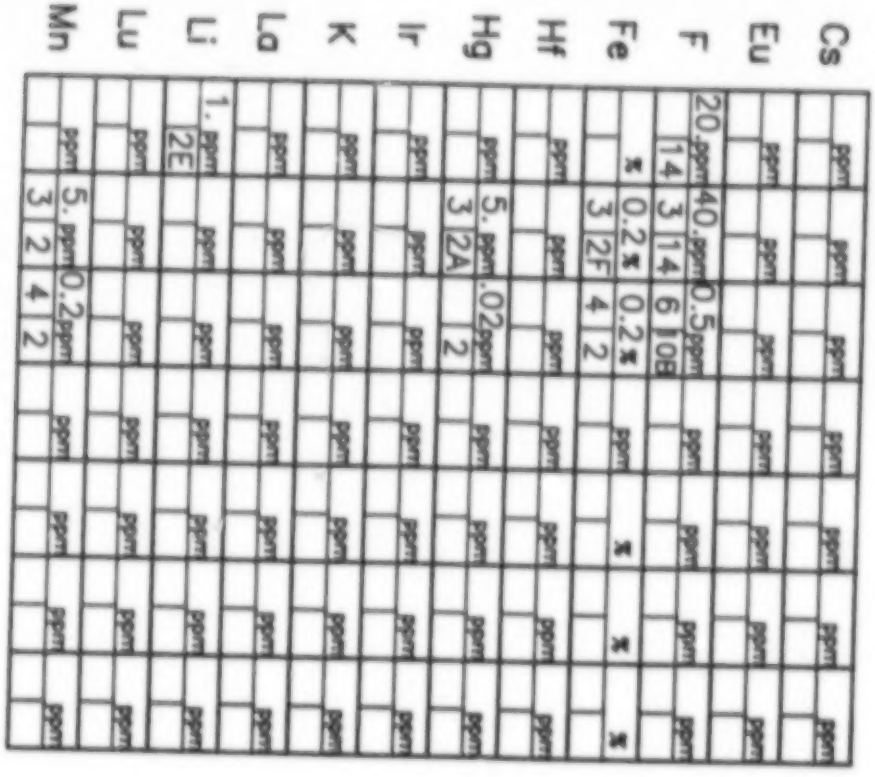
DRAINAGE SURVEYS : LAKE SEDIMENTS



1985 Lakes

1983 Lakes

1978–79 Lakes

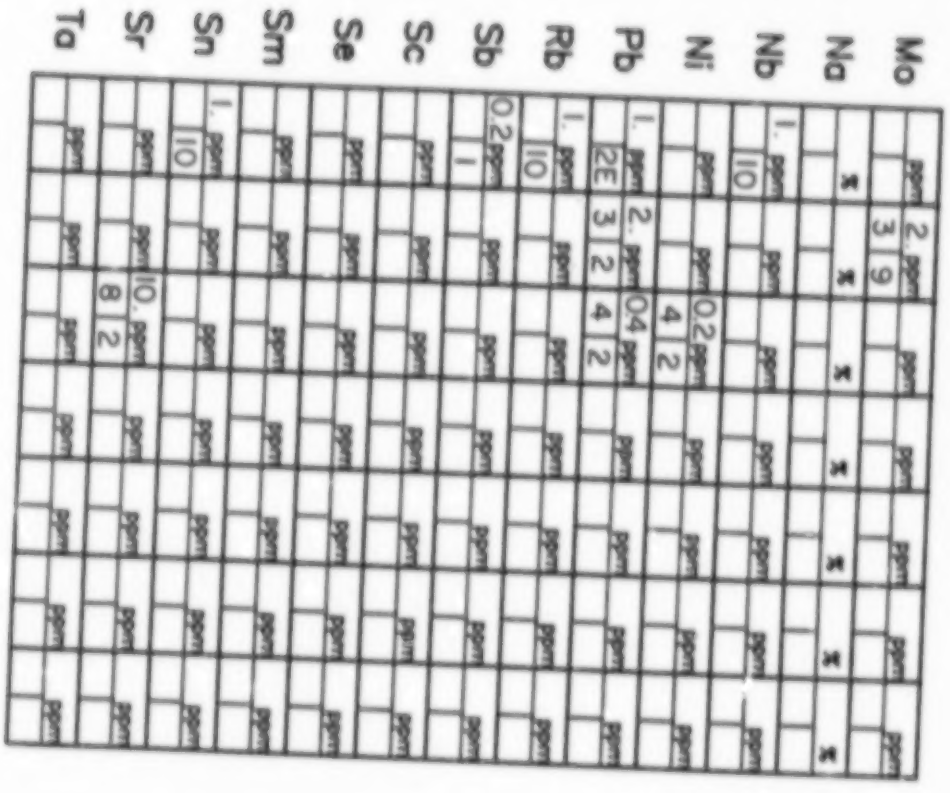


1985 Lakes

1983 Lakes

1978–79 Lakes

DRAINAGE SURVEYS : LAKE SEDIMENTS



1985 Lakes

1983 Lakes

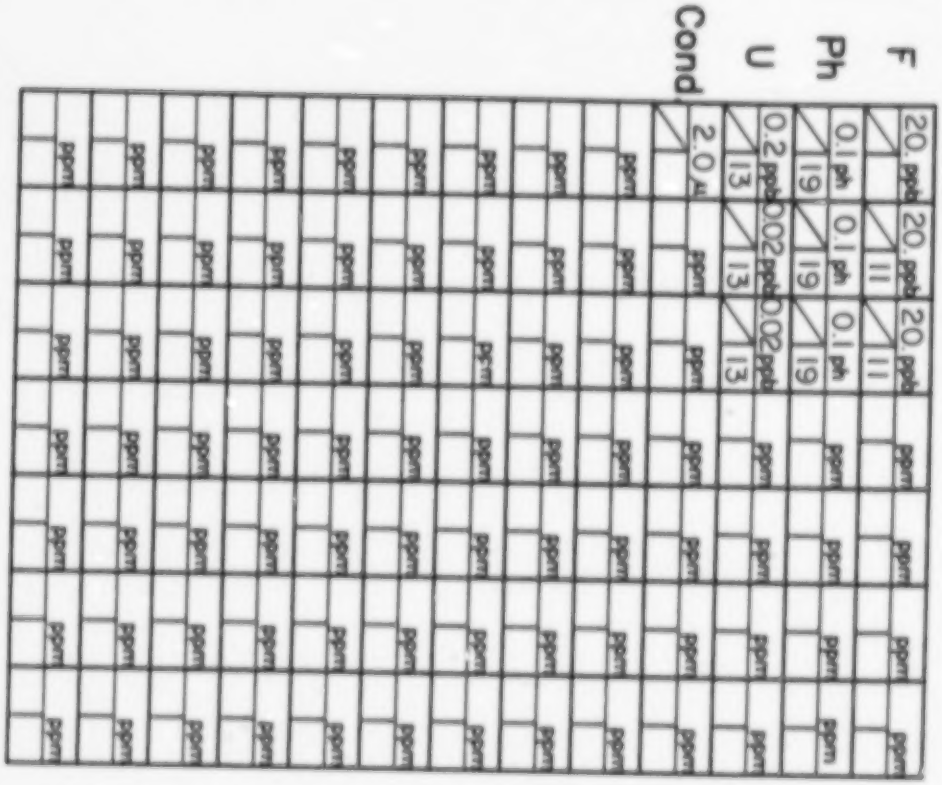
1978–79 Lakes

1985 Lakes

1983 Lakes

1978–79 Lakes

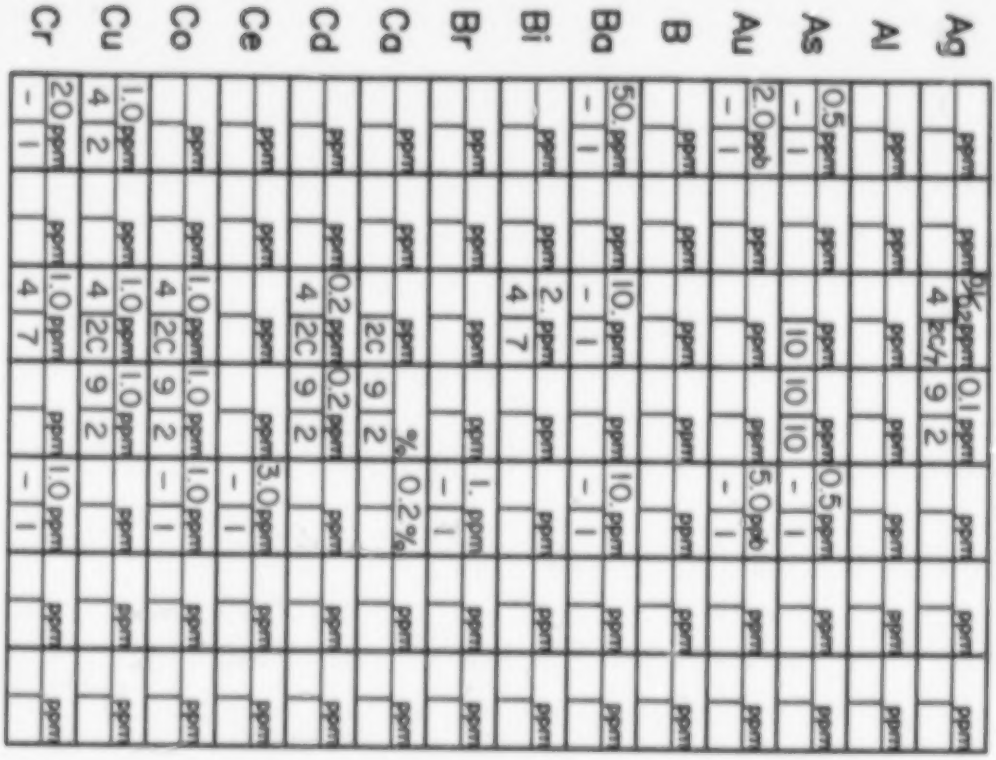
SURFACE WATER SURVEYS



1986–87
Stream H_2O

1983
Stream H_2O

1983
Lake H_2O



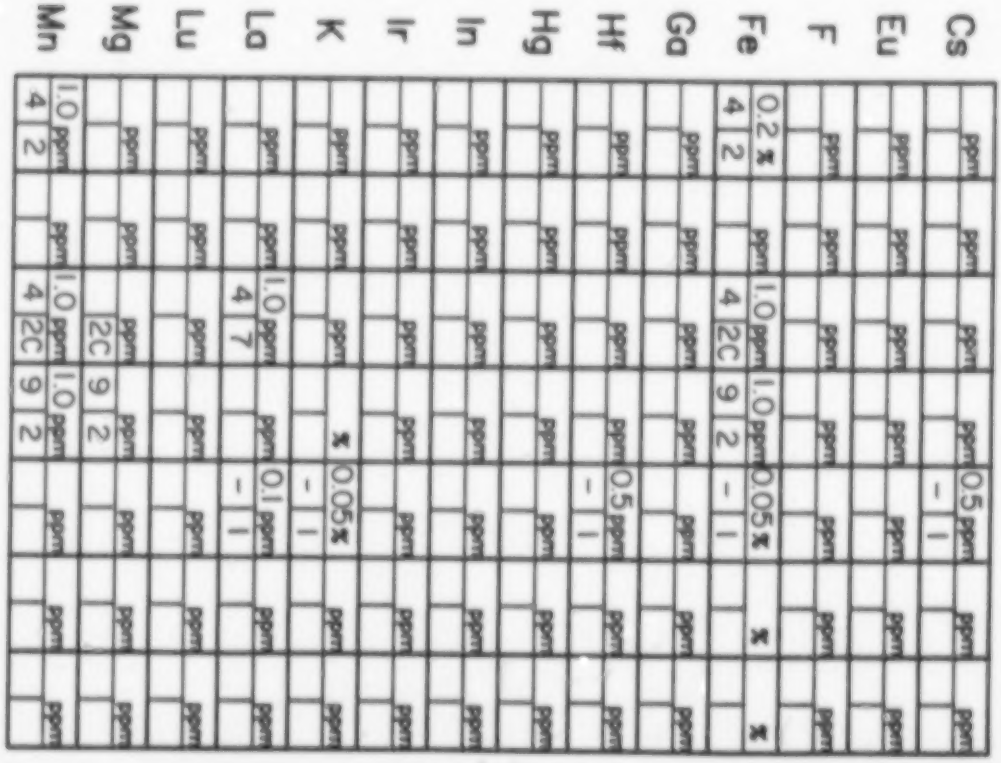
SMB Tills (−230 mesh)

SMB Tills (H.M.C.)

1982–86 N.N.S. Till

1977–85 Meguma Till

1987 Biogeochem



SMB Tills (−230 mesh)

SMB Tills (H.M.C.)

1982–86 N.N.S. Till

1977–85 Meguma Till

1987 Biogeochem

	Mo	Na	Nb	Ni	Pb	Rb	Sb	Sc	Se	Sm	Sn	Sr	Ta
SMB Tills (−230 mesh)	ppm	x	ppm	20 ppm	2.0 ppm	5.0 ppm	0.1 ppm	0.2 ppm	ppm	ppm	2/1 ppm	ppm	0.5 ppm
SMB Tills (H.M.C.)	ppm	x	ppm	2.0 ppm	4 2	- 1	- 1	- 1	ppm	ppm	14/15 24/7	ppm	- 1
1982–86 N.N.S. Till	1.0 ppm	x	ppm	4 2C	2.0 ppm	- 1	- 1	- 1	ppm	ppm	ppm	1.0 ppm	4 7
1977–85 Meguma Till	1.0 ppm	x	ppm	2.0 ppm	9 2	- 1	- 1	- 1	2.0 ppm	ppm	2.0 ppm	ppm	- 1
1987 Biogeochem	2.0 ppm	x	ppm	50 ppm	- 1	5.0 ppm	0.1 ppm	0.1 ppm	2.0 ppm	ppm	ppm	100 ppm	0.5 ppm
	ppm	x	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
	ppm	x	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm

	Tb	Te	Th	Ti	U	V	W	Yb	Zn	Zr
SMB Tills (−230 mesh)	ppm	ppm	0.2 ppm - 1	x	0.2 ppm - 1	ppm	1.0 ppm - 1	ppm	100 ppm 4 2	x
SMB Tills (H.M.C.)	ppm	ppm	ppm	ppm	ppm	ppm	4.0 ppm 15 7	ppm	ppm 4 2C	ppm
1982–86 N.N.S. Till	ppm	ppm	ppm	ppm	ppm 8 5	ppm	4 10	ppm	1.0 ppm 9 2	x
1977–85 Meguma Till	ppm	ppm	0.1 ppm - 1	x	0.1 ppm 8 -	ppm	2.0 ppm 12 10	ppm	1.0 ppm - 1	x
1987 Biogeochem	ppm	ppm	0.1 ppm - 1	x	0.1 ppm - 1	ppm	1.0 ppm - 1	ppm	1.0 ppm 20	x
	ppm	ppm	ppm	x	ppm	ppm	ppm	ppm	ppm	x
	ppm	ppm	ppm	x	ppm	ppm	ppm	ppm	ppm	x